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Edited for the Council by J. LAURENCE PRITCHARD, Fellow

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NOTICES

Election of Members

The following Members were elected at a Council Meeting held on October 6th:—

Associate Fellows.—Mr. H. J. Andrews, Major C. K. Cochran-Patrick, Mr. A. Gouge, Mr. T. C. Sharwood and Mr. M. W. Wood.

Student.—Mr. C. W. Miller.

Members.—Mr. H. G. Hiske and Mr. G. G. Parnall.

Foreign Member.—Mr. V. T. Friedrich.

Informal Discussions

A small Committee has been appointed to organise informal discussions to take place in the Library from time to time. The Secretary will be glad to hear from Members who would be willing to open discussions, with a résumé of the subject they wish to discuss. As noted in the Month's Arrangements an informal discussion will take place in the Library on November 16th, at 6 p.m., on the Autogyro.

Students' Meetings

If sufficient support is shown, it is proposed to revive the meetings held by Students in the Library. At these meetings Students read papers written by themselves and discuss them. Two prizes are offered for Students' papers, particulars of which were given in last month's Journal. If any Students are interested in these meetings, will they please send a postcard to the Secretary, mentioning the time at which they would like them to take place? In former years 8.0 p.m. was the favourite hour.

Steels Used in Aero Work

The article on "Steels Used in Aero Work," by Dr. W. H. Hatfield, which was reprinted in the Journal for October, originally appeared in the Journal for July, 1917.

Aluminium Alloys

Dr. Lea's paper on "Aluminium Alloys," which was reprinted in the August Journal, was originally published in the Journal for November, 1919.

Reviews

Through a printer's error the title of "Das Leichtflugzeug" was given incorrectly on page 548 of the October Journal. The publishers of this book are Bechholds of Frankfurt-am-Main.

XUM

The Month's Arrangements

Tuesday, November 3rd, 7.0 p.m.—Joint Lecture with the Institution of Automobile Engineers, at the Royal Society of Arts, 18, John Street, Adelphi, W.C.2. "The Evaporative Cooling of Aero Engines and Condensation of their Exhaust Gas," by Wing Commander T. R. Cave-Browne-Cave, C.B.E., Fellow.

Thursday, November 12th, at 5.30 p.m.—In the Library. "Some Problems in Aeroplane Structural Design," by Mr. H. B. Howard, Associate Fellow.

Monday, November 16th, at 6 p.m.—In the Library. An informal discussion on the Autogyro.

Thursday, November 26th, at 5.30 p.m.—In the Library. "Installation Problems in Air-Cooled Engines," by Mr. A. H. R. Fedden, Fellow.

Thursday, December 3rd, at 5.30 p.m.—In the Library. "The Control of Stalled Aeroplanes," by Professor B. Melvill Jones, A.F.C., Associate Fellow.

J. LAURENCE PRITCHARD,
Honorary Secretary.

PROCEEDINGS

First Meeting, First Half, 61st Session

A meeting of the Royal Aeronautical Society was held in the Society's Library, at 7, Albermarle Street, London, on Thursday, October 1st, 1925, when a paper by Major-General Sir Sefton Brancker, K.C.B., A.F.C., F.R.Ae.S., on "The Lessons of Six Years' Experience in Air Transport," was read by Major R. H. Mayo.

Before reading the paper Major Mayo said: It is a most unfortunate thing that we are deprived of the presence of our new Chairman to-night. As you know, it is customary for the Chairman to deliver his inaugural address at the first meeting of the Session. Sir Sefton Brancker needs no introduction to anyone here to-night. We all know about his work and the distinguished manner in which he has carried out his duties as Director of Civil Aviation. At the present time he is still out in the East on one of his frequent visits there, where he is laying the foundation for British air routes of the future. Unfortunately, he was unable to get back in time to read his paper. However, in the near future we shall have an opportunity of welcoming him as our new Chairman.

It is also unfortunate that we have not here our retiring Chairman, for we should like to thank him for his services during the last year. Colonel Tizard, as you are all aware, is a man of great scientific attainment, and he has filled the position of Chairman of this Society with great distinction. He has given up a very great deal of his valuable time to the work of the Society, and the work that he has done has had very excellent results. He has not only helped us on the scientific side, but he has also done a great deal to put the finances of the Society on a sound footing. Largely through his efforts a grant of £250 a year for five years has been obtained from the Air Ministry, which will be a very definite help to the Society.

May I take this opportunity of reminding all those who are present here to-night about the proposed extension of the activities of the Society. On September 15th we had a special meeting to consider the scheme which had been outlined in the Journal for August. I am going to read the conclusions reached at that meeting:

1. That it is important to add to the Technical Membership of the Society a Grade suitable for those of good technical and flying practical experience who are not however qualified for Associate Fellowship. Such members should pay a fee corresponding barely to their actual cost to the Society. They should have the full privileges of membership except that they should only receive the Journal if a special fee was paid. They should, however, be entitled to purchase at cost price one copy of each issue of the Journal. The fee for such membership might be one guinea with an additional guinea if the Journal is to be received regularly.

2. That informal discussions, especially of practical problems, would be an important addition to the work of the Society and would be well attended particularly by such members.

3. That 6.0 or 6.30 p.m. is to many a more suitable time than 5.30 p.m. for lectures and is certainly more suitable for discussions.

4. That the proposal to form Works Societies affiliated to the R.Ae.S. should be discussed in detail with the S.B.A.C. and should be extended to the newly-formed Flying Clubs.

5. That Aeronautical data sheets similar to those of the Institution of Automobile Engineers should be issued periodically.

6. That the Journal include very short summaries or references to aeronautical technical work published elsewhere.

I am sure that every member of the Society is anxious that this extension should take place, and I take this opportunity of asking any member who is head of a firm, or who is a designer, or head of a department in an aeronautical firm, to bring these suggestions to the notice of his staff, and get them interested.

The Council would gratefully welcome any further suggestions which members care to make as to the best methods by which such an extension of the activities of the Society may be brought about.

THE LESSONS OF SIX YEARS' EXPERIENCE IN AIR TRANSPORT

BY MAJOR-GENERAL SIR SEFTON BRANCKER, K.C.B., A.F.C., F.R.AE.S.

GENTLEMEN,

I feel far from deserving of the great honour done me in my election to the distinguished position of Chairman to this Society; and I approach with considerable diffidence the first task of the Chairman—the delivery of the inaugural address. You are all well aware of my complete lack of scientific attainment, and therefore of my inability to add to the many valuable and learned papers which have been read by past chairmen, and which have contributed so much to the development of aeronautical science and knowledge. I have come to the conclusion that the best I can do is to attempt to define to you the principal lessons learned in six years' practical experience of air transport with aeroplanes and seaplanes and to evolve therefrom the most important problems which the operators of air transport wish to place before the many capable scientists and designers who are interesting themselves in aviation to-day. Of airships we have no real experience as yet, and I must therefore leave them out of my arguments.

There are many men still who cannot take air transport seriously; they look upon it as a sort of blind alley in aeronautical progress—too dangerous, too unreliable and too costly ever to be of serious commercial value, and fit only for a camouflage under which can be hidden a military reserve for the Royal Air Force.

To these theories I find myself in the most definite disagreement. It is true that the history of British air transport so far has been disappointing in its slowness of development and discouraging in its constant demands for financial assistance—but we have made progress—and, personally, not only am I convinced that it must become one of the principal means of long distance communication throughout the world, but I firmly believe that, before many years are passed, its operation will be just as remunerative as shipping and railway transport have been in the past.

Every day brings fresh proof that in the preparation for war aviation is being steadily promoted to the premier place as a means of offensive action; I hope and believe that in commercial development aviation will outstrip the older forms of transport as an essential method of rapid communication, and that, if we guide our policy wisely, the British aircraft industry will possess as great a measure of importance to the British nation as our shipbuilding industry has possessed in the past.

During the six years that air transport has been in operation we have learnt a great deal on the administrative side—and have made our operations as regular,

as safe and as economical as is possible with the equipment available. Our personnel are not likely to be improved on very much in the future. The pilots and mechanics in British civil aviation to-day are beyond reproach, and have pushed up efficiency to the highest pitch possible with the facilities provided. Present methods of handling passengers and freight—systems of advertisement—ground organisation—may leave much to be desired; but the faults which exist are not generally the result of ignorance or lack of experience; they are the outcome of shortage of money.

But when we examine the aircraft themselves; the engines with which they are fitted and the instruments used in their equipment, we find room for great improvement everywhere, and a vast field for scientific activity.

Personally, I believe that we have arrived at a stage at which the future development of air transport towards real commercial efficiency depends to a very great extent on the ability of our designers and scientists and on the measure of financial support which we can give to their investigations and experiments.

In the course of my paper I shall quote certain figures and statistics. Before going further, I would like to express my indebtedness to the managing staff of Imperial Airways for the great assistance they have given me in my efforts to produce reliable data.

The concession of a monopoly in subsidy to a single company for operations within Europe has been criticised from some directions, but 15 months' experience leads me to think that considerable technical benefits should accrue from the new system.

Imperial Airways have become the experimental establishment of the Air Ministry for the trial of new commercial aircraft and their accessories. This innovation has already worked extremely well, and in the future the technical lessons of Imperial Airways' operations will be at the disposal of all the aeronautical bodies and should be of great value to the aircraft industry in developing new and more efficient aircraft and engines.

It is a platitude to state that the success of any form of transport depends on its safety, its reliability and its economical operation. These three qualities, however, cover most of the current problems of air transport and I propose to use them as the main headings of my paper.

Safety

In what respect is air transport dangerous? The various sources of danger may be summed up as follows:—

(*a*) Breakage of the aircraft itself in the air.
(*b*) Jamming or failure of the controls.
(*c*) Fire.
(*d*) Engine or installation failure over heavy sea or country where a safe landing is difficult or impossible.
(*e*) Error of judgment or sickness on the part of the pilot.
(*f*) Adverse weather.
(*g*) Collision.

This appears at first sight to be a somewhat formidable list, but actually the fatal accidents in British air transport since its inception have totalled only five and were brought about by the following causes:—

Error of judgment	2
Power plant failure leading to error of judgment	1
Bad weather leading to error of judgment ...	1
Collision	1

There were certain other accidents which, although not leading to fatal results, might be classed as dangerous; the causes of these were as follows:—

Error of judgment	1
Power plant failure leading to error of judgment	1
Bad weather leading to error of judgment ...	1
Power plant failure	2
Collision owing to error of judgment	1
Faulty compass	1

Summing up, all accidents which could be classed as dangerous, including those which involved fatalities, totalled 12; their basic causes were as follows:—

Error of judgment	8
Power plant failure	2
Collision	1
Faulty compass	1

In examining these figures, one fact strikes the mind at once; most of our accidents have been caused by error of judgment on the part of the pilot. Those inexperienced in aviation might say that a cure for such errors of judgment is hardly within the scope of the designer and scientist; but this is not so, and I will deal further with this point later on.

In spite of the fact that some of the prospective sources of danger enumerated by me, have led to no accidents at all during six years of hard flying, I feel that I must give them full consideration in their turn.

(*a*) Breakage of the aircraft in the air.

In the early days of aviation this was the cause of many accidents; but our designers have learnt by experience and to-day, touching wood, we should be absolutely sure that such a breakage in a normally designed aircraft could not occur on a properly maintained service, where excessive strains are not involved by everyday work. Safety in this respect can be ensured by frequent and efficient inspection, and here the designers can help. All men are human, and in the stress of high pressure traffic, inaccessible parts may miss inspection and so be allowed to corrode or decay. I would therefore urge that simplicity of design is a great guarantee of safety—every vital member should be easily seen and easy of access.

There is one problem of vital importance here for the scientist, a problem which I know is being most carefully investigated. That problem is to discover the causes of fatigue in metal and to lay down guiding principles for its detection and its elimination.

Metal is being employed in greater and greater quantities in the construction of aircraft and those aircraft are being called on to fly longer and longer hours without overhaul; thus the question of metal fatigue is of utmost interest to the operator. As I will indicate later, in my own opinion, complete metal construction must be adopted in the future, and until we know more about the fatigue of metals we cannot be quite certain that we are not walking into unknown dangers whilst making progress in other directions.

(*b*) Jamming or failure of controls.

Much the same applies to this source of danger as to that involved in the breakage of aircraft. Simplicity of design and careful inspection are the safeguards against such happenings. To avoid any chance of interference with the controls by inexpert persons, we have brought in a regulation prohibiting the ordinary passenger from being seated in the pilot's cockpit.

(*c*) I think that it is fair to say that in a well tried-out machine, properly looked after, the danger of fire in the air is negligible. The danger involved by the remote possibility of a petrol pipe breaking is guarded against by the pro-

vision of fireproof bulkheads between the engine and the crew and cabin. There is one question in this connection which designers should consider. At present all air intake pipes have their openings on the outside of the cowling in order to avoid the danger involved by a backfire. This system is a source of unreliability in cold climates, because snow is apt to get into the intake pipes and smother the engine. If the openings of the intake pipes were placed inside the cowling, this source of trouble would be eliminated. But how far is this safe? Can designers undertake that the nacelle shall be so well ventilated and drained as to ensure that a backfire will have no dangerous results?

The danger of fire in case of a crash is admitted, but can be reduced to the minimum by the careful placing of tanks and the avoidance of pressure systems of petrol feed. The use of heavy oil may render this danger more remote in the future, but the true guarantee of safety is the avoidance of crashes.

(*d*) The possibility of failure in the power plant is ever present in the mind of the pilot. I will enlarge on this very important factor later when discussing reliability. Suffice it to say here that the power plant very seldom fails so suddenly and completely as to necessitate an immediate descent, and there is nearly always sufficient power left in the engine to reach a place of safety. Herein lies one of the advantages of a two-engine machine; although it may not be able to fly on one engine, it can always carry out a very long glide.

In my list of fatal accidents, and accidents involving danger, four are associated with power plant failure. Two of these were caused by failure in getting off—one by a stalled turn on landing and one by a pancake landing. All these were with single-engined aircraft. It is possible that with two-engined aircraft three of these might have been evaded; for with one engine in operation the immediate forced landings whilst taking off might have been avoided, and the remaining power might well have eliminated the occurrence of the stalled turn.

Thus we can say definitely that the two-engined aircraft, other things being equal, is safer than the single-engined type. It is obvious that if we can design a three-engined machine, which flies satisfactorily, the chances of forced descent through failure of power plant practically vanish and this source of danger is eliminated. This statement must not be taken to mean that I admit the impossibility of producing an absolutely reliable single engine and installation, and we have yet much to learn about the three-engined aircraft.

(*e*) Error of judgment has been the basic cause of eight out of my twelve recorded dangerous accidents. These can be divided into two categories—five which were the fault of the pilot in that he took the wrong action and three which were caused by failure to handle the aircraft correctly.

The first category does not affect the designer; as examples, it includes a case of collision caused by breach of regulations and a crash caused by flying low in mist over a hilly and tree-covered country. The antidote for this sort of accident is experience combined with careful selection, good discipline and sound regulations.

The second category does affect the designer. From the beginning of aviation the designer has always been prone to assume that his aircraft would be flown by an absolutely first class pilot; consideration of the comfort of the pilot and of the ease of handling of the machine have almost always given way to demands for performance. In air transport we want a really foolproof machine, which implies first and foremost, a low stalling speed and a good initial climb when taking off.

In a normal aircraft both these qualities militate against a high top speed and a heavy load; but the economic cruising speed of 100 miles an hour demanded in normal conditions by air transport should not place any great difficulties in the way of obtaining a very low stalling speed, and it is the demand for heavy

loading which is the designer's real trouble. Already this problem is being solved by the introduction of slots and flaps and the further development of these devices is of vital importance to air transport. The specifications for experimental commercial aircraft put out by the Ministry were most of them drawn up in the hopes that designers would be able to utilise these innovations as a means of meeting our demands, but in only one case has this hope been realised up to date—that of the D.H.54 to which automatic flaps are fitted. Further experience of this machine should provide some very interesting data.

There are other items which contribute to safety from the pilot's point of view—stability in the air—a comfortable and well screened seat—a really good view ahead and all round—slow landing—and, in the big multi-engined machine, the provision of an assistant. After January 1st, 1926, all aircraft capable of carrying more than ten passengers will be compelled to carry a crew of two, the first duties of the second man being the operation of the wireless. This, of course, will be a double handicap from the commercial point of view—it involves both increase of staff and less paying load—but it has been deemed necessary for reasons of safety after long international discussion.

The possibility of sickness of the pilot in the air has been recognised in my list of possible sources of danger, but in my experience I have never known it occur. Very careful selection and frequent medical examination are probably the best antidotes to serious risk; under present regulations a licensed commercial pilot undergoes a searching medical examination every six months or after every 250 hours in the air, whichever occurs first. The provision of a second member of the crew will help to eliminate this vague source of danger, in big machines. The advisability of fitting complete dual control is a question on which I have an open mind; many pilots are strongly prejudiced against this practice, and in Government specifications we have required the second member of the crew to be so seated as to be able to change places with the pilot without difficulty.

(*f*) Adverse weather. Bad weather has seldom been the direct cause of an accident, but it does sometimes lead to bad judgment on the part of the pilot with serious results. Two of my recorded accidents are examples of this. Darkness, fog, snow and hail are our principal enemies. A reliable power plant combined with efficient wireless navigation will eliminate the danger of darkness and fog. Snow, as I have pointed out, may choke the engine unless air intake pipes are designed to prevent such an occurrence. Hail we know little about; hailstorms are of short duration and can usually be avoided; but if eventually it is found necessary to fly in hailstorms in certain parts of the world, aircraft of real all-metal construction must, I think, be employed.

The danger of lightning is often discussed, but little is really known of it. We have lately had two aircraft, one of which was not a commercial machine, struck by lightning whilst in the air. Both were marine craft flying over the sea, and both were carrying wireless sets with aerials down.

In one case the aerial and wireless set were fused, and the whole aircraft so highly magnetised that it was impossible to use the compass until it had been demagnetised. In the second case—the military machine—the engine stopped, apparently through the magneto being put out of action, and the aircraft was forced to alight on a rough sea and was eventually lost. In neither case was the pilot injured. It is therefore advisable that further investigation should be made with a view to eliminating any danger that may exist from lightning.

Generally speaking, in this part of the world, aircraft have nothing to fear from strong winds; at certain aerodromes landing may be difficult during very high winds, but there have been cases in which aircraft were crossing the Channel whilst the weather was too bad for the operation of the cross-Channel steamers. During our flight to Rangoon, Cobham and I were flying without any difficulty or danger when ships were putting to sea to avoid the dangers of the coast in

bad weather. We have no experience of typhoons or hurricanes up to date; these phenomena, however, give ample meteorological warning of their approach and aircraft should therefore be able to avoid flying into them. It is obvious that great stability and a low stalling speed will help towards the total elimination of any danger that may arise from unusually high winds.

(*g*) Collision. The only case included in my record occurred in 1922. A British and a French machine collided whilst flying along the same road in very low cloud. This was before any definite rules had been laid down for guidance to pilots forced to navigate by following features on the ground; wireless was not being used by the British pilot; and his machine admittedly had a bad view forward. Clear rules have now been published, and a similar accident should not occur again with ordinary precautions and with the volume of traffic as it stands to-day. On the other hand, when night flying and cloud flying become regular practice, we must realise that the danger of collision will increase. It is therefore necessary that our scientists should begin to consider this question and evolve some sort of automatic warning of the approach of another machine in cloud—maybe by wireless, maybe by sound, maybe by a combination of both.

There is one form of collision which must not be altogether forgotten; the possibility of colliding with birds in flight. We have had one mysterious incident, in which a pilot lost control of his machine flying over sea at a low height; the pilot's opinion was that he had been struck on the head by a sea bird, several of which were flying near him at the time, but nothing was ever clearly proved. In the East, propellers of machines getting off have been broken by kites flying over the aerodrome. I have never heard of an aeroplane encountering a flock of duck at night; such an eventuality might lead to danger of injury to the pilot, the propeller or the wing structure. The best precautions to meet such a danger will be good screening for the pilot and robust metal construction.

This concludes my review of the dangers inherent in flying. They cannot be said to amount to very much. Summing them all up, the following are the principal points on which designers and scientists can best help the operators to avoid danger:—

(1) The development of metal construction for every component of the aeroplane and further investigation into the action of fatigue on these metal structures.

(2) The provision of an infallible power plant even at the cost of extra weight and extra expense.

(3) The design of aircraft of greater stability and easier to handle than those in use to-day.

(4) The perfection of wireless navigational equipment.

(5) The elimination of the possibility that snow may choke the engine.

(6) Investigation of the effect of lightning and the development of measures to prevent any danger therefrom.

(7) The evolution of some form of automatic fog signal which will function between aircraft in full flight.

Several of these demands we shall hear of again when considering the other headings of my paper.

Reliability

I have examined the causes of the unreliability of flights actually started during the first year of operations by Imperial Airways. Administrative causes do not affect my paper; delays through defects in the aircraft itself are negligible; and the two main items are (*a*) weather and (*b*) defects in power plant. These two causes cover three quarters of the total, the balance being chiefly due to

landings to take in fuel; of this three quarters, weather is responsible for 66 per cent. and mechanical defects for 34 per cent. on the whole year; but during the winter months weather goes up to 78½ per cent., whilst in summer it drops to 50 per cent.

(*a*) I can say at once here that "weather" implies "bad visibility"; this was practically the sole meteorological cause of all these delays. Bad visibility implies fog, thick mist, or clouds so low as to make it impossible to fly along features on the ground without risk of collision with trees, buildings, hills, etc.

Now all our *aircraft* can fly in bad visibility; it is the *pilot* who refuses to fly in weather conditions in which he cannot see; and, with existing aircraft, if he did not so refuse, I should probably have had some more items to add to the accidents caused by "bad weather leading to error of judgment."

The reasons that the pilot will not fly in bad visibility conditions are fourfold:—

(i.) If he flies through fog or the clouds he fears that our existing aircraft, when heavily loaded, may be thrown out of control.

(ii.) If he flies above the fog or clouds he is apprehensive lest his power plant should fail and force him to land through the zone of bad visibility—and he also still lacks full confidence in his compass and wireless as a means of knowing exactly where he is.

(iii.) If he flies below very low clouds he is afraid of colliding with trees, church steeples, etc., or being forced to land in some impossible place if visibility grows worse.

(iv.) In all these cases he also fears that when he reaches his destination he may find it impossible to land on account of fog or very low clouds.

The pilots deserve all sympathy in their struggles with bad visibility conditions; the achievements of some of them in this respect have been wonderful, and they have frequently accomplished feats of air navigation voluntarily for which orders from higher authority would not have been justified. It is therefore of vital importance that our best brains should be concentrated on the problem of producing aircraft, which will not call for such a high standard in piloting, and with which operations in bad visibility can be demanded without injustice to the navigating crew.

First and foremost we must have aircraft of greater stability; whether the stability should be inherent in the design, or whether it should be obtained through some automatic mechanism, I cannot say. The most promising means of obtaining stability appears to be the gyroscope at the moment, but I doubt if anything like the full development of inherent stability has been obtained as yet; I venture to say that the original B.E.c designed and constructed by the Royal Aircraft Factory in 1913 and fitted with the 70 h.p. Renault engine possessed a greater measure of inherent stability than any aircraft which has been produced since. This I attribute to the fact that military specifications have never really insisted on a high measure of inherent stability. However, Mr. Sperry, and I think a few other inventors, claim that they can give perfect stability by means of gyroscopic control. Already the gyroscopic rudder control has lifted us a very appreciable step forward in our progress towards a proper measure of stability; an experimental set of this apparatus has been in operation for some weeks with Imperial Airways and, in spite of some mechanical weaknesses, it has won high praise from the pilots who have used it, and it has relieved them of one of their anxieties—directional control—when flying in clouds.

Air transport demands an aircraft which will look after itself in the air just as a ship does on the water; human error will thus be eliminated; courses will be

set through clouds without any fear of the aircraft getting out of control; and the pilot will be free to navigate in the true sense of the word.

The pilot's apprehensions regarding his power plant can be relegated to the next section, where I will consider material failures in detail; his lack of confidence in his means of navigation to-day is perhaps not so fully justified as is his dissatisfaction on other counts. Our latest compasses are really very good if properly placed, carefully watched and efficiently maintained. Our directional wireless, although perhaps a little clumsy in system, has worked extremely well, so long as the wireless equipment carried on the aircraft has been kept right up to the mark. Improvements are necessary, but they are not so vital as on other heads. A system of wing coils to replace the trailing aerial is being developed, and also a receiving set by which the pilot can estimate his bearing to a ground station himself without asking for it, as is done under present conditions. The elimination of the trailing aerial is important, as when flying low in very bad weather the aerial sometimes has to be reeled in just when it is most required.

The fourth source of anxiety to the pilot—the possibility of finding absolutely impossible weather at his terminal aerodrome—is a more difficult problem. First, however, let me say that it is very seldom that landing is quite impossible on a good aerodrome, and secondly, that so far as safety is concerned, the pilot should be fully informed of conditions by wireless before he arrives, and if the weather is impossible, he should always be able to land somewhere else within reasonable distance of his objective. However, to attain perfect regularity, we must devise a means of competing with what to-day is considered as impossible weather.

With our existing wireless equipment, it has already proved possible to bring an aircraft practically over an aerodrome in bad visibility. Having arrived at this point, it is necessary to evolve a means of bringing it down safely on to the aerodrome even in fog. We have tried new systems and colours of lighting in fog with some success; the Neon lights up to date have generally given the best results. We have tried in miniature the Leader Cable with satisfactory results—the leader cable being a cable laid along the ground and carrying a current from which aircraft can be guided by their pilots so as to fly directly over the cable. At Croydon, during the coming winter, I hope that we shall be able to try out at full scale a complete system of landing in fog. The aircraft will be led up to the aerodrome through its wing coils; it will discover the right line of approach and alighting by balancing the signals picked up from a leader cable; and a line of Neon lights laid along the leader cable on the ground will show the pilot where to flatten out as he glides down in accordance with the leader cable indications. No doubt numerous weaknesses and difficulties will disclose themselves in the course of our tests, and it behoves every expert in sound, light and electricity, who wishes to help in the development of real air transport, to turn his mind to the difficult and interesting problem of landing an aircraft in fog.

So much for unreliability caused by weather; I will now turn to the second main cause, mechanical defects in the power plant, a category which should be more susceptible to human correction than that due to the weather.

I have already indicated that this represents the cause of from 21½ per cent. to 50 per cent. of our unreliable flying, according to the time of year. An examination of the defects found in engines, which fail to run their routine number of hours in the air satisfactorily, should give us a good estimate of the reasons for this measure of unreliability.

I have studied carefully the causes of engines being removed before their proper date of overhaul, during operations carried out by Imperial Airways during the year ending May 1st, 1925. These figures affect only two types of engine, both water-cooled; but they give very definite indications of the lines on which improvement can be made in the future. For obvious reasons I will not consider

these two types separately, nor am I at liberty to give the totals of the various cases of failure.

I find that the really definite sources of trouble are 28 per cent. in the water system, 19 per cent. valve breakage or distortion, and 10 per cent. oil circulation, these three items accounting for 57 per cent. of the whole. Another 23 per cent. covers actual breakages of material, such as cracked crank cases, broken housings and casings and other failures of material. Of all these failures which demanded the removal of the engine, only 7 per cent. were so serious as to cause an immediate stoppage of the engine, and again only two of these were in single-engined machines; of this 7 per cent. there was only one case of a broken connecting rod and three cases of breakage in the reduction gear.

I think that these figures are really satisfactory because so many of the failures are comparatively easy of correction; it must be realised, of course, that the cases dealt with are only those which necessitated the removal of the engine. I have no record of what delays were caused by magneto trouble, carburettor defects and faulty petrol supply which could be corrected without removing the engine.

What can we learn from this? First that water-cooling has been our greatest weakness lately: the simplest way of curing this trouble would certainly appear to be the employment of air-cooled engines and we already have types of great reliability which will shortly be put into regular commercial service.

Then valves. We are developing a sleeve valve engine for which it is claimed that this 19 per cent. of valve trouble will be totally eliminated; but even without this, I feel something can be done to improve the wear and tear qualities of the valves of ordinary practice. Oil trouble can surely be avoided by more careful detail in design. So the causes of the most prevalent diseases of our standard engines—water, valves and oil—appear to be comparatively easy to avoid in the future.

Again, an examination of the 23 per cent. of removals caused by breakage of some part or other shows that they were mostly minor items which can be attributed to vibration, fatigue in metal, and perhaps to some extent to faulty fitting. The three cases of breakage in the reduction gear—and these, of course, are very serious items—point to the advisability of using a direct drive engine; certain of the new types about to be put on service have a direct drive, but generally speaking, the aircraft designers are almost unanimous in demanding a geared-down engine as being absolutely essential if they are to obtain the maximum lift from a given measure of horse power.

I would here remind all designers of the obvious fact that an installation failure is every bit as serious as most engine failures. During the early stages of the war the design of installations rather fell between two stools, and I believe, even now, that the question of installation is apt to take second place in importance to that of the engine or aircraft proper. I venture to say that the average magneto is not so perfect as the much criticised aero engine, and only lately we have had cases of blocked petrol pipes and air locks in the petrol system which surely might have been avoided if a little more importance had been attached to that part of the aircraft's anatomy.

Designers may claim that I have put too great a measure of blame on them for these failures, whereas actually the human fallibility of the mechanic may have a good deal to do with these troubles, particularly those associated with valves, oil and minor breakages. I agree, but I would urge acceptance of the plea that simplicity and robustness of design are the best means of making an engine "fool-proof" and of giving the average mechanic a fair chance of doing himself justice in the maintenance of any particular engine. It would be quite possible to design and construct a highly efficient engine which no human mechanic could keep in flying condition when subjected to hard work.

I must allude here to the possible introduction of heavy oil engines for use in aeroplanes in the future. I frankly confess that I know very little about this innovation, but it does seem that a heavy oil engine should avoid valve and ignition troubles, and I understand that it is considered feasible to employ air-cooling for an engine of this type. I realise that this possibility is still some way off, but I will deal with it further when considering economy.

The question of multiple engines must be considered here as a means of avoiding forced landings and so eliminating perhaps the whole of the unreliability due to mechanical failure.

No two-engined machine that I know of can be counted on to reach its destination carrying an appreciable load with one engine out of action; in other words, it does not surpass the single-engined machine in reliability although, as I have indicated already, it certainly appears to give a greater measure of safety. The two-engined machine with its engines in tandem offers the best endeavour towards reliability, but of this type we in England have no experience.

In order to avoid complication in control, the three-engined aircraft seems to deserve consideration next after the two-engined type. We have little experience yet of the three-engine unit, but on paper a three-engined machine should always be able to reach the end of its stage with one engine stopped even with an almost full load. We have several such aircraft under construction, and this time next year we ought to know whether this is the right solution or not; the most serious item of doubt is the effect of the slipstream from the front and centre engine on the propellers of the two engines mounted on the planes. If we find insuperable difficulties here, we may have to go to four-engined machines with engines in tandem, which system has already been proved to be aerodynamically sound.

Personally, however, I still refuse to believe that it is impossible to design and construct an absolutely reliable single-engined aircraft.

That practically covers all the main reasons, other than those of a purely administrative character, of unreliability in operation. If we sum them up, the most important subjects for the study of the technical experts, in order to better matters in this respect, are:—

(1) Once more, the development of metal construction for every component of the aircraft and the further investigation into the action of fatigue on all metal structures, particularly those included in the aero engine.

(2) Once more, the provision of an infallible power plant even at the cost of extra weight and expense. The direct-drive engine is obviously more reliable than the geared engine, and it is for the scientist to endeavour to obtain as good a lift from an ungeared engine as from a geared-down engine.

(3) Once more, the design of aircraft of greater stability and ease of handling, than those in use to-day, particularly with a view to flying long distances through cloud without fear of loss of control.

(4) Again, the perfection of wireless navigation equipment.

(5) Again, the elimination of the possibility that snow may choke the engine.

(6) The evolution of some system of guiding an aircraft safely into an aerodrome in fog.

(7) Very close attention to the reliability of all components of the installation.

(8) The development of a satisfactory heavy oil engine, without exceeding the total weight per horse-power of "engine plus four hours' fuel," of existing petrol engines.

It will be seen that several of the most important scientific investigations and items of technical progress necessary to attain perfect reliability are also demanded in the interests of safety, and at no point do these two interests clash in any way; a very satisfactory deduction from every point of view.

Economy

We now come to the real bugbear of air transport—its cost of operation. There are many comparatively intelligent individuals who maintain that aeroplane transport cannot pay in this generation or even during the next; some will say never, except for the carriage of mails over particular routes.

The history of British air transport in economical progress is a sad one; we have passed through a series of changes in Government policy and in organisation and administration, which have nullified all efforts towards steady progress in effecting economies.

Finally, we have placed the activities of British air transport within Europe in the hands of a purely commercial organisation with a clearly defined measure of Government financial assistance promised for a period of ten years, of which 1½ years have already elapsed. This company had an unfortunate start, and it is now reaping the full harvest of the troubles which were sown through the initial errors of its policy. However, I hope that its worst moments are over and that we shall soon be given a demonstration of maximum possible efficiency with a minimum of expenditure.

One serious economic difficulty of air transport is the fact that nothing but the best is good enough. First, the standard of personal skill and individual responsibility necessary in a pilot is greater than that required from a similar individual in any other form of commercial transport. Then the whole inspection and maintenance organisation for the operation of aircraft must be of a higher standard than in any other walk of life—partly because of the danger involved by any failure in the air and partly on account of the comparative delicacy of the aircraft and engines themselves. Further, both aircraft and engines require that measure of lightness combined with great strength which must involve high cost in manufacture.

I fear that transport by means of aeroplanes and seaplanes must always be expensive when compared with other forms of transport. Trains, ships and airships maintain themselves in their own particular mediums without expenditure of energy; therefore the whole of their available horse-power can be applied to propulsion. In aeroplanes and seaplanes, on the other hand, a proportion of the available horse-power must be expended on lifting their own weight from sea or land and raising it to a safe height for navigation. I think it was Sir Charles Parsons who stated that air transport was always hauling up an inclined plane.

I have already indicated the lines of progress along which greater reliability and safety can be obtained; unfortunately, in nearly every case, the improvements demanded to gain these ends involve greater capital expenditure or greater cost of operation. For example, metal construction calls for more expensive aircraft although it will save in maintenance; low stalling speed and quick climb must involve loss of paying load; more reliable engines, or multi-engined aircraft, result in greater weight of power plant per horse-power and consequent reduction of paying load; better and safer navigation involves the carrying of a second member of the crew, again detracting from the paying load and incidentally increasing the salary bill. So my paper up to the present point has not held out much encouragement to those who wish to reduce the cost of air transport. However, there are possibilities.

I will first enumerate the chief items of cost of operation as apart from

those of administration, and then endeavour to indicate how scientific progress can assist to bring these down very considerably.

The most important items of expenditure on the actual operation of any service are as follows:—

(*a*) Cost of fuel and oil.
(*b*) Pilots' and mechanics' flying pay.
(*c*) Engine maintenance and overhauls (man-hours and spares).
(*d*) Aeroplane maintenance and overhauls (man-hours and spares).

I will deal with these first and discuss depreciation and insurance later, as these two latter items have not been included in operating costs in the figures in my possession.

(*a*) Fuel and oil at present account for about 30 per cent. of these operating costs—a very big item indeed; as an example, a standard W.8 Handley-Page expends more than tenpence a ton-mile on petrol and oil. The possibility of an appreciable reduction in the cost of petrol in the near future seems very remote, and we must look to the scientist either to obtain the necessary horse-power with a lesser expenditure of fuel, or to evolve a means of employing a cheaper form of fuel.

So far as I know, very little had been accomplished towards the reduction of fuel consumption per horse-power until quite lately; but I understand that now the blending of certain ingredients with standard petrol has given a distinct gain in horse-power for weight of fuel consumed.

On the other hand, we have made very great progress towards the production of an engine burning heavy oil with a total weight per horse-power not seriously exceeding the modern petrol engine. The extra weight of this engine is compensated for by the fact that the actual weight of the fuel consumed per horse-power promises to be something approaching 20 per cent. less than that of the petrol burnt in existing engines. Here indeed is a step in the right direction, the cost of heavy oil can, I suppose, be assessed at about one fifth of that of petrol; so we see that in an aircraft of similar horse-power and qualities as the Handley-Page, about eightpence per ton-mile could be saved by the fitting of heavy oil engines. Heavy oil has its drawbacks; it is dirty and it creeps; but I think that these defects can be combatted and with such a saving in their fuel bills in prospect it is hardly possible for operating companies to refuse it a trial. Fortunately the airship scheme covers considerable expenditure towards the development of heavy oil engines and the result of these researches and experiments will be of great value to the operators of heavier-than-air craft.

The adoption of heavy oil fuel would almost certainly necessitate the use of all-metal aircraft; wood and fabric would be too susceptible to the creeping tendencies of heavy oil.

(*b*) The cost of pilots' and mechanics' flying pay is a comparatively small item, but is worthy of consideration. The rate to-day is, I believe, 10/- an hour; the equivalent of 1¼d. to 1½d. a mile according to the speed of the aircraft.

This rate was based on the numbers of hours flying per annum that it was considered fair and safe to demand from the pilot in order that he might earn a fair wage. As aircraft improve in stability and ease of handling, and as power plants become really reliable, the strain of piloting will be reduced and the time spent in the air can be increased. Pilots to-day are flying as much as 135 hours in a month during the summer without adversely affecting their health, and I think the highest total attained in ten months' operation by an individual pilot last year was 650 hours. As conditions improve, these hours will undoubtedly be lengthened considerably. How rates will adjust themselves I do not pretend to know, but increased hours of work must lead to economy in operating costs.

(*c*) The next item of operational costs, the maintenance and overhaul of engines, is the biggest of all. It represents about 44 per cent. of the total of the items given in the list above. Maintenance and overhaul are very closely inter-related; it is not only necessary to assess the maximum number of hours an engine can be run with safety; there is also a maximum number of hours after which the cost of overhaul rises out of all proportion to the extra hours flown.

To-day this latter figure has been assessed at 300 hours with one particular standard type of engine, with a top overhaul after 200 hours. Actually, however, engines have to be removed frequently before this period has expired.

In that portion of my paper dealing with reliability, I have given the causes of removal of engines for overhaul before their proper period of time—and an examination of these causes gives the items on which man-hours and spare parts can be saved when better material is available. You will remember that the four most serious troubles in our present engines sprang from the water system, the valves, the oil circulation and the breakage of parts, usually of small importance. In two of these categories, water system and oil circulation, totalling 38 per cent. of the whole, the cost of spares is scarcely involved; they are almost entirely a question of man-hours. The other two, valves and breakage of parts, totalled 42 per cent. of the whole, and involved considerable expenditure in spare parts as well as in man-hours. All these cases involved many man-hours wasted in removing faulty engines and installing sound ones. From this I think I am safe in saying that an increase in the capital cost of engine and spares would be justified, if thereby the frequent removal of engines could be avoided and the hours before overhaul lengthened.

Apart from this, the antidotes to the particular troubles enumerated can be summed up as the adoption of air-cooling, the elimination of poppet valves and increased robustness in design. Air-cooling may involve increased fuel consumption, and it is most important that investigations should be applied to the reduction of consumption in the air-cooled engine. The abolition of poppet valves would cost nothing, but the general increase in robustness of the engine must add to its weight. All things considered, however, I am of opinion that an increase of weight in the engine would be justified from the economical point of view, if only an appreciable number of man-hours can be saved thereby. There seems little doubt also that the heavy oil engine should be more durable and call for less work in maintenance than the petrol engine.

(*d*) The next item of operating cost is the maintenance and overhaul of aircraft, to which can be allotted about 20 per cent. of the total. In this I include the installation of fittings.

The first cry of the operator is for simplicity and ease of access to all important components. In this respect I fear that war methods led designers into bad habits. In 1914 complicated designs were accepted as necessary evils. Squadrons had a large establishment of mechanics and new designs were developed without any regard to their economic maintenance. These evil habits have continued since the war, and it is only the economic pressure of commercial operation which has brought vividly to notice the fact that much of the money spent in maintenance could be saved if a little more attention had been paid to simplicity in design and ease of access to important components. The cost of the labour necessary to maintain any particular type of aircraft is directly proportionate to the number of nuts, bolts, split pins, pulleys, turnbuckles, lengths of wire, etc., which are included in its design and to the time required to reach, inspect and change all moving parts, and the various components of the installation, such as magnetos, filters, carburettors, pumps, etc.

Many of the defects in this respect in existing aircraft could be eliminated in future by a little careful thought and common sense, and I would urge

designers to call in someone well versed in the problems of practical operation to assist them when they are considering these details in any new type. Cheapness of maintenance must not be lost sight of whilst evolving the details of the aerodynamic design of a new aircraft. The thick-winged cantilever monoplane has certainly proved easiest to maintain in an efficient flying condition. It is claimed for the Fokker types that the planes need not be touched for a period of 12 months, and I believe the Junker types last even longer without attention. But how far their cost of overhaul will compare with that of normal biplanes, and how far aerodynamical efficiency may have been sacrificed, still remains to be proven.

Unfortunately for us, lack of continuity in policy and administration has made it very difficult to obtain reliable data regarding the deterioration of the aircraft in use. Up to date, some of our aircraft have flown for as much as 2,000 hours, covering perhaps 170,000 miles without undergoing thorough overhaul—and these operations have extended over 18 months. Inspection has revealed, however, that it is not wise to permit such long periods of operation with wooden aircraft, and consequently the following system has been brought into force.

After every 250 hours' flying, a machine undergoes what is termed a "dock overhaul," which includes opening up the fabric and closely inspecting every really important part of the structure. This may throw the aircraft out of work for as long as three days, and involves the application of a considerable number of man-hours.

In conjunction with this procedure, Government regulations demand the renewal of the airworthy certificate once a year. This involves a very thorough inspection throughout by Government officials, which can be carried out during a dock overhaul.

From our experience up to date, it is generally believed that after three years' service an aircraft should be completely overhauled—in fact reconstructed to all intents and purposes. It is hoped that she will then be able to work for another three years, at the end of which she may have to be scrapped. Experience points to the likelihood of a more frequent dock overhaul than every 250 hours being necessary during the second period of three years. The six aircraft of the present Imperial Airways fleet which have flown most have averaged 260,000 miles each since manufacture. They were taken over from the old companies and have all been flying a little more than three years. All this costs money. Most of the defects discovered lately during periodic inspection have been directly due to the perishable nature of wood and fabric and the action of metal fittings on the wood. I am therefore forced to the conclusion, with the experience at our disposal, that the adoption of all-metal aircraft must be the next important step towards reducing costs of maintenance. The most important scientific problems in this connection are the evolution of light metal structures; the elimination of fatigue and the prevention of corrosion. The capital cost of these metal aircraft must be considerably greater than wood so long as only small numbers are required, but I believe that this extra cost will pay for itself easily in the resulting saving in man-hours and overhaul materials. This is certainly borne out by the experience of the Junker firm, who frequently leave their all-metal monoplanes standing in the open throughout the year without serious deterioration.

It must be borne in mind that the benefit of any improvements in design leading to longer hours between overhauls will be twofold; not only will the actual spares and man-hours expended on the aircraft be lessened, but the amount of work each aircraft can accomplish in the year will be increased more and more as its periods of detention under overhaul grow fewer and shorter. This will result in a smaller fleet being required for any particular service than is the case at present.

Before leaving the question of possible reductions in operating costs through technical progress, the factors of depreciation and insurance must be mentioned. The rate of depreciation of an aircraft is probably approximately proportionate to its cost of maintenance; our experience is not yet sufficient to state definitely what the rate of depreciation is; but, as I have already stated, six years is at the moment considered to be the full life of a wood and fabric aircraft which has been in continuous hard work. Actually the oldest machine of the Imperial Airways fleet, which had been flying about six years, has I believe just been struck off as time-expired. It is to me absolutely certain that the life of a metal aircraft must prove to be considerably longer.

Regarding depreciation in engines, we really know nothing definite yet. I know of no engine that has been condemned for reasons other than severe damage or obsolescence. There are several engines running to-day with over 1,500 hours in the air, and I believe one has done 2,000 without any apparent depreciation.

Insurance is a very big factor in costs. Since the beginning of our activities in 1919, insurance rates have varied between 12 per cent. to 30 per cent. per annum on the capital cost of an aircraft, regardless of the number of hours it spent in the air during the year; I believe, however, that negotiations have been in progress with a view to putting insurance on a mileage basis.

These rates sound high, but it must be remembered that any small mishap, not necessarily incurring any danger, may result in heavy claims against the insurance companies, and I understand that, consequently, they have lost money in the insurance of air transport up-to-date. The obvious way to lower insurance rates is to increase the standard of reliability and safety, and I can safely say that the various lines of progress indicated as being necessary to improve reliability and safety will all tend to lower insurance rates when they are accomplished. In addition, if insurance is obtained on the annual premium basis, the more work that the aircraft can do the lower will be the incidence of insurance on costs per mile; another incentive towards obtaining aircraft easy to maintain and engines of long running life.

I have now dealt at some length with the various possibilities of reducing the costs of operation in air transport. Before going further, it will be as well to summarise the conclusions arrived at under this head.

The items of technical progress demanded are as follows:—

(i.) Reduction in the weight of fuel consumed per horse-power, particularly in air-cooled engines.
(ii.) The introduction of some cheaper fuel than petrol.
(iii.) Once again, an improved power plant even at cost of extra weight and expense.
(iv.) Once again, the introduction of all-metal aircraft even at greater capital cost.
(v.) The development of the thick-winged cantilever monoplane or biplane without external struts and bracing.
(vi.) Investigation and prevention of corrosion in metal.

It will be seen that two of these steps towards greater economy in operation are similar to those already demanded for safety and reliability, and that none of the others need necessarily clash with the requirements of these two latter essentials.

So much for the reduction of operational costs for a fixed load; I now propose to examine the only other important method of effecting economy in operation; the carriage of a greater paying load per horse-power for a fixed operational cost.

A glance at the percentage of incidence of the four main items of expenditure in operation will disclose the fact that the cost of operation varies directly with the horse-power of the power plant. Seventy-four per cent. of the total cost can be attributed to the maintenance and the fuel consumption of the engines; further,

the capital value of engines and of most normal commercial aircraft are closely related to the horse-power employed, which again extends its influence to depreciation and insurance. It is for this reason that the contract with Imperial Airways for the European services has been modified from a purely mileage basis to a horse-power mile basis.

If we accept my plea that operational costs are directly proportionate to the horse-power employed, two problems present themselves to the designer in his struggle towards producing a really economic aircraft.

(i.) How can he carry more total weight per horse-power than is the practice to-day?

(ii.) How can he improve the ratio of the weight of paying load to the total weight of the aircraft?

These two problems are closely bound up together and yet offer different aspects. To my mind they form the most difficult and perhaps the most important objective for the designer. All my suggestions so far have been concrete and fairly clearly defined, but here the initiative must lie with the designer and his field of action is a very wide one.

To commence from actual facts, the existing standard commercial machines give us the following results:—

Type.	Horse Power.	Total Weight per sq. foot. (lbs.)	Total Weight. per horse power. (lbs.)	Paying Load per horse power. (lbs.)
de Havilland 34 ...	... 440	13.5	16.4	3.1
Handley-Page W.8	... 710	8.6	17.6	3.85
Supermarine Sea Eagle	... 365	9.95	16.6	2.19

It is on these figures that we must endeavour to make a definite improvement.

First, how can a greater total weight per horse-power be carried with safety? In approaching this problem, it must be realised that the basic difficulty is not to fly with a greater weight, but to leave the ground safely under the various adverse conditions of atmosphere and soil which present themselves in practical operations. For instance, the D.H.34 probably expends something between 450 and 480 horse-power in its initial take off, whereas it cruises comfortably at 95 miles an hour with only about 350 horse-power. With this factor in mind the following solutions present themselves:—

(*a*) Increased wing area.
(*b*) A good climbing wing section.
(*c*) The employment of flaps, slots and other similar devices.
(*d*) The introduction of variable pitch propellers.
(*e*) The "ground boosting" of engines.

(*a*) Increased wing area must spell reduction of speed. When considering new designs of commercial aircraft in the drawing office, speed is apt to lose its importance in the eyes of the designer, and he is prone to sacrifice this quality to attain the apparently more commercial attributes demanded. The Dutch Fokker and German Junker are good examples of this tendency. But speed has a very high commercial value. It must be remembered that, given a fixed horse-power, the faster a journey is accomplished the less does it cost per mile—the items of fuel consumption, maintenance, flying pay, wireless and probably insurance per mile all go down; and further, reliability and punctuality are enhanced. It is only the paying load per horse-power that suffers.

Considerable experience of racing with darkness, and bad weather, and of long journeys carried out against high winds with only barely enough petrol to reach the objective, has perhaps biassed me a little in favour of speed, but I believe that under normal conditions a cruising speed of 100 miles an hour is necessary for the regular and efficient carriage of passengers and mails; indeed

for mails I anticipate considerably higher speeds will be demanded in the future. Overseas also it is often necessary to fly long stages against strong prevailing winds, factors which demand a good turn of speed in the interests of economy; for this reason military opinion has put the proper speed for the Egypt-Iraq service at 120 miles an hour. Unfortunately, this speed requirement is in direct opposition to the demand for a low stalling speed on the heads of safety and reliability, and I suppose that a heavily loaded machine cruising at 100 miles an hour must always have a comparatively high stalling speed unless some form of variable wing device be employed. It is quite possible that goods services will fly at much lower speeds than 100 miles per hour; delays through weather, shortage of fuel, etc., will not affect this class of traffic so seriously.

So, whilst still maintaining my demand for at least 100 miles an hour for normal traffic, I would suggest that for goods traffic designers should seriously consider the problem of how slow it is possible to fly economically, and, presumably, increase of wing area is the direct road to the solution of this problem. In connection with the consideration of speed, it is as well to remember that an improved design in propellers may literally give us something for nothing; the remarkable results obtained by the " Reid " type of propeller at high speeds show the possibility of further progress in this direction.

(*b*) My next suggestion was the evolution of a better climbing wing section than those used at present; this would also presumably have the additional good quality of lowering the stalling speed. Here I admit that I am very much out of my depth, but I do feel that we have by no means come to the end of possibilities in this direction. The thick-winged type of aircraft flying at present certainly appear to offer great possibilities in this direction, but I cannot say how far speed and perhaps lightness of structure have been sacrificed to attain the qualities they evidently possess.

(*c*) Now I come to the next method of obtaining a safe " get-off " with a heavy load; the employment of flaps, wing-slots and other devices, such as variable camber, variable area, etc.

The flap system may be described as a form of variable camber. It has been with us for a long time; the first S.E. type constructed at Farnborough before the war was fitted with flaps and they were embodied in two or three types, both Government and private, during the war. The exact measure of the effect of flaps I believe to be somewhere about a ten per cent. gain in lift when fully applied, and the general adoption of this method of increasing the lift whilst getting off and landing has not proceeded so fast as its efficacy deserves. The latest development in the shape of a flap which adjusts itself automatically to the speed of the machine is fitted to the new Air Ministry cross-Channel type, the D.H. 54, and will be very thoroughly tried out in the near future.

The fitting of slots to the wings, particularly near the leading edge, both claims and promises better results than those given by flaps; but practical progress has been aggravatingly slow, and it is only lately that we have had a remarkable demonstration of the power of this system to reduce the stalling speed of a standard aircraft. Now about five other types are to be so fitted and definite experience should soon be available.

I have seen many suggestions involving systems of variable camber and systems of variable wing area, but, so far as I know, none of these types has ever been developed into a sound practical proposition.

The system of fitting of flaps, slots, etc., has two advantages over other means of carrying an increased load; it enables a fast machine to be flown slowly and so gives it more time to climb over the available aerodrome and so to clear any surrounding obstacles; and, in addition, the stalling speed can be reduced either when desired or automatically.

(*d*) I have mentioned next the introduction of variable pitch propellers as a means of improving the "get-off." Here is a problem, perfectly simple and obvious in principle, which has proved extremely difficult to put into practice; even now, personally, I have never seen a variable pitch propeller in satisfactory operation, but I understand that the experts claim that all difficulties have been successfully eliminated and that this new aid to economy is practically with us.

(*e*) Next comes the development of so-called ground-boosted engines. By this means, without appreciably increasing the weight of the power plant, a very much increased horse-power can be obtained during the initial climb; to get the best out of this system a variable pitch propeller is necessary. I have heard various figures, ranging from 25 per cent. to 50 per cent., mentioned as the measure of the gain in horse-power. The employment of these two latter developments does not bring with it the advantages of a slow take-off speed and a low stalling speed—but combined with the fitting of flaps and slots, and perhaps an improved wing section, a very great improvement in the total weight carried per horse-power should be possible without danger. With all these developments I do not see why a total increase of 25 to 30 per cent. should not be possible in the near future; in other words, we should be able to design even now an aircraft cruising at 100 miles an hour and weighing fully loaded 25 lbs. per horse-power, which will be safe and easy to fly.

I think that I have now covered the most obvious means of carrying a greater total weight per horse-power; the next problem of the designer is to increase the ratio of the possible paying load to this total permissible weight to its utmost. This must largely be a question of designing a structure which shall be lighter, but which cannot be of less strength than present practice; broadly, two lines of progress offer themselves—improved detail in design and better material. The paying load is naturally largely affected by the amount of fuel carried, but as this is dictated by circumstances and the speed of the aircraft, I will not consider it under this head. However, it should be borne in mind that any saving in weight of fuel consumption per horse-power will at once directly benefit the weight available for paying load.

Concerning detailed design, I am in no way qualified to speak. Our newest experimental machines offer, I think, a distinct saving in structural weight per horse-power. Of the foreign types in which a definite attempt has been made to include a rigid wing covering as an integral part of the wing structure, the metal Junkers of the original type resulted in greater weight, and I think the Fokker works out to about the same as our practice; and the Rohrbach promises to be lighter. I cannot help feeling that this is the right line of progress towards economising weight and that further experience will bring about tangible benefits.

An inspection of the table on page 576 reveals the fact that the paying load ratio of the small flying boat is exceedingly bad. On the other hand, some of our leading designers hold the view that the really big flying boat or seaplane (perhaps 2,000 horse-power and above) will work out to be lighter than the aeroplane and will give in consequence a better ratio of paying load. A most interesting and valuable scientific investigation at the present moment would be an endeavour to assess the most efficient size for an aeroplane and a flying boat; there must be some point at which the ratio of paying load to total loaded weight must be at its highest, but so far as I know, we have not any notion as to where this point lies, although it is often stated that there is a size above which the structural weight increases out of proportion to the disposable load.

As a scientific problem, however, I ought to ask for the size of the aircraft which will give the highest possible ratio of useful load (including crew, instruments, fuel and paying load) to total weight of structure and power plant.

I come finally to the question of improved material. Here, again, I am inexpert and ignorant, but I feel that metal, particularly in large aircraft, must

eventually show a considerable saving on wood. The research and experiments on the material which is to be used on the big Government airship are calculated to encourage this opinion, but, with my lack of real knowledge, I will leave this question for others to enlarge on—perhaps in a separate paper.

This concludes my examination of possible methods of increasing the paying load per horse-power. It will be as well once more to review the salient conclusions which derive from my arguments. To progress along this line of improvement, the following are the most important technical developments necessary :

(i) The development of slow-flying aircraft with the greatest possible carrying capacity for the transport of goods.

(ii) Further investigation and experiment in the qualities of the thick-winged aircraft both in wood and metal.

(iii) Very full investigation and experiment into the combination of flaps, slots, the ground-boosted engine and the variable-pitch propeller.

(iv) Scientific investigation into the optimum size of aircraft for economic results.

In these investigations it must be assumed that 100 miles an hour cruising speed is necessary in aircraft engaged in regular passenger and mail services.

There is one other point which concerns the development of aircraft towards a commercial basis on which I have not touched. The eventual success of air transport must depend on the traffic it attracts, and it is necessary to consider for a moment what the public wants. For the carriage of mails and goods I think that it is fair to say that the requirements of safety, regularity and economy already enumerated will, when attained, attract all the traffic necessary for success. But passengers require more than this; they require comfort.

The standard of comfort in an aircraft in good weather is already high, and progress is being made towards the really satisfactory heating and ventilation of the cabins; but there are two factors of discomfort which demand the attention of designers, scientists, and even doctors—noise and air-sickness. The noise of the exhaust has already been reduced with some success, but the noise of the engine itself, and still more the noise of the propeller, are causes of considerable annoyance and discomfort to a certain number of the passengers. The engine will no doubt grow more silent as designs develop; for instance, the sleeve-valve engine should be more silent than existing types; but the reduction of the noise of the propeller appears at present to be an insoluble problem. The best line of attack appears to be a thorough investigation of the problem of producing an approximately soundproof cabin—and even before that is arrived at, a good deal can be done towards the elimination of reverberation and drumming in the cabin. We have this problem under scientific investigation at the moment.

The reason for air-sickness has not yet been satisfactorily explained. It cannot be exactly the same as seasickness, for good sailors are often bad airmen, and vice versa. I suspect that noise and bad ventilation have had something to do with this trouble up to date, and in addition I rather suspect that the change of pressure caused by climbing affects some individuals adversely. In any case to-day air transport has, I think, undeservedly earned a bad reputation for causing sickness, and I should be deeply grateful to anyone who can discover the reason for this human failing and prescribe a palliative.

I have now enlarged at some length on practically all possible technical means of improving air transport up to that point at which it will be able to take its place amongst other methods of travel, transport and communication as a sound commercial proposition.

To save confusion of mind after so long a dissertation, I must capitulate the lines of progress, which amongst all those indicated are, in my personal opinion, the most urgent and important.

I would unhesitatingly place the production of an unfailing power-plant as being first in importance.

Real progress in the reliability of the engine and its installation, and an appreciable addition to its length of life before overhaul, will do more in the immediate future towards the attainment of perfect safety, great reliability and high economy than any other development.

Whether the necessary standard of reliability will be attained by the employment of several engines or by the perfection of one, I will not prophesy. Both systems have their advantages and drawbacks. So long as engines are fallible, so long must multi-engined aircraft be necessary for absolute reliability; an additional advantage of the multi-engine type in large aircraft is the fact that the production of a number of small units is easier and cheaper than the construction of a smaller number of larger units.

On the other hand, the single engine offers the best aerodynamic results. I personally lean towards the opinion that the eventual solution will be the employment of two or three engines carried in a central engine room, but that meanwhile the single-engined aircraft has great possibilities if sufficient attention is directed towards attaining perfect reliability of running.

Next in order of importance would I place the vexed problem of attaining greater stability and ease of handling, whilst increasing the measure of lift by means of the various auxiliary devices to wing surface which offer themselves. Thereby will safety, reliability and paying load be very appreciably increased, though economy in maintenance may suffer.

Next, in my opinion, should come the further development of all-metal construction, particularly in connection with the thick-winged type of aircraft. Included in this line of investigation are the questions of fatigue in metal and corrosion. In the course of my arguments, metal construction has shown itself to be of vital importance in our progress towards greater safety, reliability, economy in maintenance and increased carrying power.

Finally, amongst the four most important objectives, I would mention the further development of the heavy-oil engine for use in aeroplanes and seaplanes. This engine is already considered by a large body of expert opinion to be essential for the successful operation of airships. In the aeroplane its first value will be the saving of cost in fuel, but it also appears to offer greater reliability and a lesser expenditure on maintenance.

It may be worth while here to try to visualise for a moment the measure of reduction in costs which might be attained by the successful accomplishment of some of the technical objectives outlined above.

I will take as my basic factor a standard aircraft closely approximating to one of those operating to-day.

This aircraft carries a total load of 18 lbs. per horse-power, of which only 3·5 lbs. per horse-power represents paying load. Its cruising speed is 85 miles an hour and its endurance about 4½ hours. Its cost of operation, including only fuel, maintenance and overhaul, flying pay and wireless, is 3/- a ton-mile. These figures are not exact statistics, but they are based on experience and can be guaranteed as a reliable standard of existing conditions.

In addition, I will assess overhead charges, including insurance and depreciation, at 2/- a ton-mile. This is an imaginary figure, but is, I think, sufficiently high. We have therefore a total cost of 5/- a ton-mile.

Let us examine our costs of operation first. Earlier on in this paper I have indicated that they are divided as follows:—

Fuel and oil	30 per cent.
Maintenance and overhaul of engines ...	44 per cent.
Maintenance and overhaul of aircraft ...	20 per cent.
Miscellaneous	6 per cent.
	100 per cent.

If some of the improvements I have outlined come about, I can see no reason why the fuel bill should not be reduced to one-fifth; engine maintenance to one-half; and aircraft maintenance to three-quarters, of their present figures. This would result in a saving in operational costs of more than 50 per cent.

The cost of operating the standard aircraft at once drops to 1/6 a ton-mile, without overhead charges.

Next I have visualised the possibilities of increasing the total load carried per horse-power. Let us suppose that we attain 24 lbs. per horse-power; this does not seem an outrageous supposition considering what has been done experimentally and taking credit for the various new developments already in progress. This increase of one-third to the carrying power would give us, other things being equal, a paying load one-third greater for the same cost of operation, *i.e.*, $1\frac{1}{3}$ ton-miles for 1/6, or $1/1\frac{1}{2}$ a ton-mile.

Finally, let us imagine the ratio of paying load to total load to be increased, as seems certain in the future. The ratio in the standard aircraft is approximately one-fifth; let us imagine this increased to one-fourth, *i.e.*, 6 lbs. per horse-power instead of 3.5 lbs.; a little arithmetic shows that the cost per ton-mile will then fall to $10\frac{1}{2}$d.

The overhead charges must also decrease. As safety and reliability increase, insurance and depreciation will drop steeply; in addition, this same enhanced measure of safety and reliability will give a great impulse to the already growing traffic, which in its turn will lower the incidence of the remaining overheads on the ton-mile. A reduction of 50 per cent., *i.e.*, from 2/- to 1/- a ton-mile, would not be an exaggerated estimate even in the early stages of improvement.

The final result of these calculations is that a rate of $1/10\frac{1}{2}$ a ton-mile at 85 miles an hour cannot be considered out of reach even with the developments we have in view to-day. The higher cruising speed of 100 miles an hour and the increase in the capital value of the fleet necessitated by the adoption of metal aircraft will throw up expenses somewhat, but even allowing as much as $4\frac{1}{2}$d. a ton-mile for these items, we reach the result of 2/3 a ton-mile at 100 miles an hour including all costs.

I have no doubt personally that there is a vast amount of traffic available in the shape of passengers, parcels, and perishable goods, for which such a rate can easily be obtained in many parts of the world if a reasonable measure of security and punctuality be assured by experience. I do not look upon these figures as vague and unreliable; some of my claims may be too optimistic, but others will certainly prove to be too conservative. I have tried to prove that the great steps in progress visualised in this paper are within the grasp of our scientific experts and designers; but we must face the fact that brains, energy, money and time must be wholeheartedly dedicated to the pursuit of these objectives.

This paper would hardly be complete unless I enumerated the experimental commercial aircraft at present being developed through orders placed by Government with private firms, and explained the particular objectives which inspired the development of each type.

Three specifications were drawn up in 1922 for the following types:—

(i) An improved "cross-Channel" machine cruising at 100 miles an hour and carrying 5 lbs. of paying load per horse-power. This specification was an endeavour to produce a machine which could carry its load at a cheaper rate per ton-mile than is possible at present.

(ii) A "Middle East" machine fitted with three air-cooled engines and capable of flying 500 miles against a 30-mile-an-hour wind. Paying load as great as possible. The specification was dictated by the conditions prevailing in Iraq and the Persian Gulf.

(iii) An " Imperial Communication " machine, fitted with three engines and capable of reaching Malta without refuelling. It was hoped that such an aircraft could reach Australia by an " All-Red " air route.

Orders have since been placed for (i) and (ii). Specification (iii) proved too difficult to accomplish; a machine with this range could have been produced, but its paying load would have been too small for practical purposes. The type was therefore abandoned for the present. For specification (i) the de Havilland 54 is the first representative. I do not think that she will carry as much as 5 lbs. paying load per horse-power, but she will come near it and marks a very distinct advance on any existing type. She is fitted with automatic flaps, and a single Condor engine.

There is another of this type ordered with three air-cooled engines, but her development has been so much delayed that she may have to be cancelled altogether. Owing to being fitted with three engines, it is unlikely that her paying load per horse-power will be as high as that of D.H. 54.

The representative of the type (ii) is the Siddeley-Armstrong " Argosy " fitted with three Jaguar engines. She will be our first real three-engined machine designed for a specific purpose from the start. She is partly of metal construction. During 1924, Imperial Airways came to the conclusion that this type, although designed for the Middle East, would also meet European conditions excellently, and so ordered two more machines.

At a later date three more specifications were put out by the Air Ministry :—

(iv) A flying boat with two air-cooled engines totalling about 500 horse-power. The specification was based on the demand for a small flying boat for pioneer work and short-distance services in various parts of the world, cheapness in original cost and maintenance being of great importance. 500 horse-power is considered to be about the lowest possible for a really airworthy boat with an appreciable paying load, and the two-engine system has certain obvious advantages in the design of flying boats.

(v) A large passenger-carrying flying boat with three engines capable of flying 500 miles against a 30-mile wind. This is intended to meet the conditions existing on the Calcutta-Rangoon service or some similar route over water.

(vi) A freight-carrying aircraft to carry about 9 lbs. of paying load per horse-power for $4\frac{1}{2}$ hours. The anticipated cruising speed of this machine is from 60 to 65 miles an hour. This specification was dictated by a desire to discover what is the greatest total load per horse-power that can be carried on a regular freight service.

Aircraft to meet these three specifications have all been ordered or are just about to be ordered.

In addition to these, two all-metal twin-engine flying boats and a very large all-metal three-engine aeroplane are on order. These are not being produced for a particular service, but in order to test thoroughly a very promising system of metal construction.

Further specifications are being drawn up for a mail-carrying machine of high speed, a survey machine and a " cheap maintenance " machine, which latter I hope may be all-metal.

In addition to the aircraft enumerated above, the Fairey Freemantle, the Supermarine Swan and the Vickers Vanguard are about to undergo operational tests with Imperial Airways.

The Fairey Freemantle was originally ordered with the specific purpose of flying round the world, and she might still be the first aircraft to circumnavigate the globe on the spares she could carry with her. She is an example of the long range float-seaplane suitable for light traffic.

The Supermarine-Swan is a normal two-engine flying boat designed to carry passengers and freight; she can be fitted with amphibian gear. She should give us valuable data regarding the best methods of arranging accommodation for various classes of traffic on flying boats.

The Vickers Vanguard is a normal two-engine machine designed to accommodate a large number of passengers; it is intended to carry out studies in lighting, heating, ventilation, silencing, and the comfort of passengers generally on this aircraft.

This list, of course, does not cover the many experiments which are being made in slots, heavy oil, sleeve-valves, metal construction, etc.

It will be seen therefore that large sums are being spent by Government on the development of commercial aircraft. It is scarcely a Government responsibility—all healthy trades carry out their own experimental work; but unfortunately at present the condition of air transport can hardly be called healthy. France and Germany are spending large sums of money on this form of development, but it is impossible to assess exact amounts with the information available. The United States have refused all artificial assistance, but have allotted funds most generously to their Government-owned air mail service between New York and San Francisco.

The following comparisons of subsidy given and mileage flown is a good guide as to the measure of importance which these three countries and ourselves attach to air transport. The figures given are those for the year 1924-25 :—

Country.	Direct Subsidies or State Service in the case of U.S.A.	Miles Flown on Regular Service.	Passengers Carried.	Freight and Mail Carried. (Tons.)
Great Britain ...	£131,500 (*a*)	825,000	13,500	507
France ...	£521,356 (*b*)	2,249,000	16,277	1,515
Germany ...	£245,000 (*c*)	2,562,866 (*d*) (2,100,000)	57,911 (*d*)	274
U.S.A. (*f*) ...	£597,826 (*e*)	1,853,251	—	60 million letters.

(*a*) Will be £224,000 in 1926-27, declining to £173,000 in 1930-31; £87,000 of these amounts is allotted to the Egypt-India service.
(*b*) Francs reckoned at 90 to £1.
(*c*) Marks reckoned at 20 to £1.
(*d*) These figures include joy-riding.
(*e*) Dollars reckoned at $4.60 to £1.
(*f*) Government mail service only.

These figures are interesting and instructive. We claim that our system of subsidy is most economical and best calculated to bring air transport up to a self-supporting standard in the shortest possible period of years. At the same time we must remember that, even when aircraft are produced which will pay their way on routes which offer a good volume of traffic, there are many desirable and valuable services in the more undeveloped portions of the Empire which will still need financial assistance on account of lack of traffic in their early years of development. Subsidies are unnatural and undesirable, but it seems obvious that if any nation is justified in spending money on the development of non-paying lines of communication, it is certainly the British Empire.

Gentlemen, this ends my honourable task. I fear that I have made but a clumsy endeavour to bring before you the most burning problems of air transport to-day.

I am convinced of two facts: first that we cannot attain commercial success without considerable further technical progress, and secondly that we cannot ensure this technical progress without a growing body of operational experience.

The operator and the designer therefore must advance side by side in full co-operation; and it was with a view to assisting in this co-operation that I wrote this paper.

In my opinion, the exploitation of air transport and the development of commercial aircraft are activities of prime importance to the British Empire. To-day, the production of military aircraft offers great rewards to designer and constructor alike; and consequently the vast possibilities of commercial aviation are inevitably overlooked. There will come a day, however, when the demand for military aircraft will sink into insignificance, beside the requirements of the air routes of the world.

We, as a nation, must keep our place in the front rank of this new industry; we depend on our communications for our existence to a far greater degree than any other people in the world; and unless we maintain these communications at the highest pitch of efficiency and rapidity made possible by every new scientific, engineering and mechanical development, our great Empire will assuredly melt away into the mists of the Past.

TABLE 1.

ACCIDENTS IN BRITISH AIR TRANSPORT SINCE AUGUST, 1919.

Cause of Accident.	Fatal.	Dangerous though not fatal.	Total.
Error of judgment	2	1	3
Power plant failure leading to error of judgment	1	1	2
Bad weather leading to error of judgment	1	1	2
Collision owing to error of judgment ...	—	1	1
Power plant failure	—	2	2
Collision	1	—	1
Faulty compass	—	1	1
Totals	5	7	12

TABLE 2.

ENGINES REMOVED OWING TO DEFECT BEFORE RECOGNISED OVERHAUL DATE.

Defect necessitating removal.	Percentage of the whole.		
Water system	28%	=	57%
Valve breakage or distortion	19%		
Oil circulation	10%		
Failures of material, *e.g.*, cracked crank cases, broken housings and casing, etc.	—		23%
Miscellaneous and indefinite defects	—		20%
	Total		100%

N.B.—Of all these failures, only 7 per cent. were so serious as to cause an immediate stoppage of the engine, and two cases only relate to single-engined machines; of this 7 per cent. there was only one case of a broken connecting rod and three cases of breakage in the reduction gear.

TABLE 3.

ANALYSIS OF OPERATIONAL COSTS OF STANDARD BRITISH COMMERCIAL AIRCRAFT.

Fuel and oil	30%
Maintenance and overhaul of engines	44%
Maintenance and overhaul of aircraft	20%
Miscellaneous	6%
	100%

TABLE 4.

STANDARD BRITISH AIRCRAFT.

Type of Machine.	Horse power	Total weight per sq. ft. (lbs.).	Total weight per h.p. (lbs.).	Paying load per h.p. (lbs.).
De Havilland 34 ...	440	13.5	16.4	3.1
Handley Page W.8 ...	710	8.6	17.6	3.85
Supermarine Sea Eagle ...	365	9.95	16.6	2.19

TABLE 5.

BRITISH AND FOREIGN AIR TRANSPORT.

Country.	Direct Subsidies or State service in case of U.S.A. £.	Miles flown on regular service.	Passengers carried.	Weight of goods and mail. (Tons).
Great Britain	131,500 (*a*)	825,000	13,500	507
France ...	521,356 (*b*)	2,249,000	16,277	1,515
Germany ...	245,000 (*c*)	2,562,866 (*d*) (2,100,000)	57,911 (*d*)	274
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(*d*) These figures include joy-riding.
(*e*) Dollars reckoned at $4.60 to £1.
(*f*) Government mail service only.

Discussion

Major Mayo said: It is unfortunate in many ways that Sir Sefton Brancker is not here to answer any points that may be raised. If anybody wants to make any criticisms of the paper, however, it gives them an opportunity of doing so without fear of an immediate reply from Sir Sefton. I will, of course, record any criticisms or comments that may be made and place them before Sir Sefton when he comes back.

I see that several of our most experienced air transport pilots have come to hear Sir Sefton's paper, and I shall ask them to open the discussion.

I regard the contribution of the pilots towards the development of air transport as of the utmost importance, and without the very excellent services they have rendered we never should have got as far as we have to-day.

Captain Barnard said: I should like to commence by saying that I am surprised to hear that it is considered that pilots have been responsible for by

far the greatest number of accidents by their errors of judgment. I feel that the paper is a very excellent one, and has, I am pleased to notice, been written from the standpoint of a pilot rather than from the critic who stands on the ground. The Mecca of Civil Aviation is twofold—regularity and comfort. To be regular is to be safe, and provided we can only put up a really first-class regular service and a high degree of comfort, there is no form of transport that can hope to compete with us.

There are three distinct components of air transport—traffic, mechanical, and the air side. With regard to the traffic side, you may think that does not offer many difficulties to the pilot. Supposing, however, this department overloads a machine, or loads it badly, it is the unfortunate pilot who has to get off with the machine and overcome the difficulties raised by the mistake. If a mechanic is slack or inefficient, or a radical engine failure occurs in flight, the pilot has to solve the difficulty. Finally, there is the biggest snag of all—that of coping with fog. It is therefore hardly surprising that pilots are responsible for errors of judgment. Many of the problems a pilot is called upon to solve have no satisfactory solution.

It is certainly possible (even with the equipment at present at our disposal) to fly long distances through the thickest of fog. Many pilots in Imperial Airways have flown through dense fog distances upwards of 150 miles. It is not so much a question of individual pilots being able to do this, but their ability to make 100 per cent. use of the organisation placed at their disposal. Nothing can be done, however, at the moment, if one has engine failure. If you have a hundred miles of low-lying fog, and the engine fails in or above it, an accident will probably occur. Therefore I would place in the premier position of importance the necessity of producing aircraft which even in the event of engine failure can be piloted safely to the next scheduled stopping-place. The machine must be stable, or semi-stable. Too large a proportion of a pilot's attention is devoted to the actual flying of the machine, and as he has some forty things to attend to, the other thirty-nine do not get the attention they deserve, to the possible detriment of the regularity of the service.

Only second in importance to the reliable functioning of the aircraft and engine is the whole question of wireless control. I sometimes feel that even those fairly intimately connected with aviation as a whole do not really realise this vital fact. I would go further and say that in my opinion had wireless not been available to us, *commercial* air transport could never be other than a farce. One has only to consider a few of the otherwise almost insuperable difficulties with which the regular air line pilot is constantly being confronted to realise the truth of this; true, he may fly dangerously low in poor visibility and often blinding rain, risking unseen obstructions (particularly in little-known mountainous country), depending upon his luck and his ability to read a map, to enable him to deliver his often valuable cargo (live or otherwise) to its destination, but no one who really believes in the future of Civil Aviation can imagine that this state of affairs is either a solution or will long be permitted.

The only alternative is to fly through or over the fog. In either case the pilot urgently wants to know:

1. Exactly where he is and what ground course he is making.
2. Approximately the positions, courses and heights of other aircraft in his vicinity.
3. Wind, speed and direction at various heights along his route.
4. The weather conditions on the ground at the landing grounds and aerodromes on his route.
5. Any information which may affect the safety of his craft or the comfort of his passengers which has come to the knowledge of those on the ground since he left.

All these may be and normally are obtained by means of wireless. Difficulties, however, are many, the chief of which are:

1. The failure of the machine's wireless set.
2. Jamming due to many machines urgently asking for information at once.
3. Night and/or Coastal Direction Finding errors which may lead to totally misleading information (if any) being given to the pilot.

I would suggest:

1. The maintenance and overhaul of aircraft wireless sets being regarded by the Air Ministry exactly as is the maintenance and overhaul of aircraft or engines (all mechanics to hold A.M. licences, etc.).
2. (A) At suitable intervals along the route erect wireless "Beacons" (which operate more or less on the lighthouse system) and by fitting the aircraft themselves with D.F. apparatus, an unlimited number of aircraft can obtain "positions" or "bearings" without any jamming.

   (B) Let a "Traffic Officer" on the ground at the terminal aerodrome definitely control the aircraft in flight by wirelessing instructions to the various machines concerned to climb, descend, bear to port or starboard, as he considers necessary. He will, as is done at present, be equipped with a large scale map upon which small models of the various aircraft in flight are moved according to their latest reported (by wireless) positions.

   (C) The introduction of telegraphy instead of the present system of telephony will do much to lessen jamming, and this, coupled with rigid adherence to prearranged times and/or places of transmission, should almost eliminate the present difficulties.
3. "Night" and "Coastal" errors in D.F. bearings have been found by experiment to be less when the aircraft takes a bearing on the ground station than *vice versa*.

In order to avoid the necessity of the pilot flying the last few miles very low with all its attendant risks, the Leader Cable System should be installed and developed at the first possible moment at all terminal and main aerodromes.

Much has been made of the desirability of increasing the paying load, but it appears that this hardly states the full case; what is wanted is not so much increased pay load per trip as per annum, and I think I am not overstating the case if *I suggest that even at the present moment and without further experimental work* it is possible to build aircraft and so to organise the air routes that any pilot of reasonable ability and experience could guarantee to operate 362 days out of the year.

There are two other points which I think might receive the close attention of aircraft designers.

Firstly, the making of the power unit, the engine installation and the fuel tanks a completely separate unit, so that at each refuelling depot this unit could taxy away under its own power and a new unit the engine of which had just received at least two hours' expert attention should attach itself. It is obvious that the present minimum 45 minutes' refuelling wait could easily be reduced to ten or fifteen minutes, making for economy, and the engines, instead of having to do upwards of nine hours' flying without expert inspection, would never do more than, say, three hours, making for safety.

Secondly, I believe a great deal of the air-sickness at present suffered by some 50 per cent. of air passengers is due to noise, reverberation and smell. Much of this could be avoided by mounting the power units as far behind the passenger cabin as possible.

Mr. HINCHLIFFE said: I consider Sir Sefton Brancker's paper extraordinarily sound and thorough, but being so comprehensive it would be impossible to deal with every point to-night.

As a pilot, however, I cannot refrain from expressing my regret that Sir Sefton Brancker has placed so much stress upon the "error of judgment on the part of the pilot," and that he has attributed such a high percentage of accidents directly to this cause.

I do feel that reference might also have been made to the great number of successful forced landings without accident of any kind due entirely to the skill of the pilot.

Unfortunately the pilot has been killed in each of the crashes included amongst those alleged to be due to "error of judgment," and the true version can therefore never be known.

Many things can happen to cause a pilot to crash fatally, but the dead pilot cannot explain and the wrecked machine can give no clue.

Engine defects, a broken wing, jammed controls and many other troubles can but rarely be detected from even the most careful examination of the wreckage.

Only the other day the wind screen of a certain machine suddenly broke in the air, and one large piece struck the pilot in the face, almost stunning him. Now had the pilot actually been knocked unconscious, or had he been blinded, a crash would have been inevitable and another verdict of "error of judgment" would have been given.

In one of the crashes included in this category by Sir Sefton Brancker, the unfortunate pilot found himself with a fully-loaded machine over the centre of a town. Circumstances arose which prevented his keeping the machine in the air and he had one of two alternatives—either to glide straight ahead and crash into the houses, certain death to all, or to attempt to turn back with the possibility of stalling. The pilot in question chose the latter, stalled the machine and all were killed. But surely such a case is not "error of judgment"?

In the fraction of a second he decided upon the lesser of two evils and showed great presence of mind when confronted with insuperable difficulties.

Now as there was no means of escaping disaster, and as this was apparent to onlookers, it would seem just a little uncharitable to me to saddle the blame upon the dead pilot. If not for his sake, then for the sake of his relatives, such a verdict should be withheld if possible.

This is a subject concerning which I could speak at length, were time to permit.

The question of advisability of low landing speeds has been raised in Sir Sefton Brancker's paper. I entirely agree with this, providing always that it is combined with controllability.

During the last few years I have been operating upon the Continental services in a machine of somewhat high landing speed, but its wonderful controllability right up to stalling speed more than compensated for its slightly higher landing speed.

Colonel BARRETT-LEONARD said: I think we must all agree that this examination of the air transport problems of Civil Aviation is most thoughtfully and thoroughly done, and draws our attention to lines of development which may lead to considerable improvement in the means which we employ in Civil Aviation.

I should like to say that I am representing Imperial Airways Ltd. here to-night. I do not think Sir Sefton Brancker had the slightest intention of reflecting in any way upon our pilots. Were it so, however, the Directors of Imperial Airways Ltd. would warmly resent any such reflection. I should not have taken this opportunity of complimenting the pilots had they not placed the

construction they had upon the author's statement. It gives me pleasure to say that no one could wish for better pilots, who do not merely pilot the machine but take a keen and very intelligent interest in anything that will improve the service or the material which they handle.

Dr. HELE-SHAW said: I wish to preface my remarks by saying that I am sure the author of the paper in using the words "error of judgment" had not the slightest intention of implying culpable error of judgment. One knows the terrible dangers pilots have to contend with both mechanical and atmospheric, which dangers require, often without warning, a decision where out of a hundred possibilities only one is a safe one. Very few people except airmen would like to face emergencies of this kind as a means of livelihood. The author with his great experience of flying knows perfectly well that rarely, if ever, the airman makes an avoidable mistake.

General Brancker, with his well-known modesty, has disclaimed any scientific attainment and invited scientific men to come forward and solve various problems in aeronautics. Scientific men will be grateful that he has stated these problems so clearly and plainly. I will refer to only one of those which he has dealt with, namely, the design and construction of a variable pitch propeller.

This subject presents a great fascination not merely from the point of view of mechanical design of such propellers, but from the interesting and complex study of the behaviour of such a propeller in the air. It is to be hoped that the Society will devote an evening before long to a discussion of a question of such great interest which from the beginning of the late war has occupied the minds of designers of aircraft.

The author has alluded to one aspect of the variable pitch screw, namely, its use in getting off the ground, and from the point of view of speed this is most important, as there have been many fatalities which possibly might have been avoided with a better "get off." But there are other aspects of importance in the variable pitch airscrew, one being great possible economy, for if—as stated in one case—an engine took 480 h.p. to get off the ground, whereas it only requires 350 h.p. for cruising purposes, this is obviously carrying something like 30 per cent. additional power for getting off purposes. I have heard it stated that 10 per cent. of additional power is a common figure.

The ideal conditions would undoubtedly be the employment of the airscrew in such a way so that the pitch would be varied automatically to suit all conditions, in order that the engine might be maintained always at its highest efficiency, whatever the atmospheric resistance, except at the get off, when hand control could be used to effect the best results.

A further consideration for variable pitch is the possibility of reversal of pitch for an aeroplane when reaching the ground or a seaplane on reaching the water. This could just as easily be effected as mere pitch variation. Landing on earth or coming up to moorings at sea would lose half their terrors.

Mr. HANDLEY PAGE said: I think General Brancker in his paper rather lays the onus on everybody but himself. He says that the organisation of Civil Aviation and its future development is perfect, but the aircraft designer does not produce the goods, and the pilots make errors of judgment. I should like very strongly to dissent from that view, and join in the expressions already put forward by other speakers in this discussion. It is very largely due to the skill of the pilots that there have been so few accidents.

I have been writing a paper on "Accidents" for the Brussels Air Congress, and have been astonished to find that for every 45 flights that are commenced, one is interrupted because of engine trouble. That on the average every 45th flight in these days of engine design and installation should end in a forced landing seems to me remarkable. If a few breakdowns occur on the railways

you hear all about it. What would the public say of a service where the engine broke down in every 45th journey? If we are going to make progress in Civil Aviation we must have an engine that is less likely to break down. I do not agree that we can have an infallible engine. I think it is perfectly impossible to have infallibility in an aircraft engine. We ought to avoid this danger of stoppage as far as possible by installing more than one engine, and the safest way seems to be to provide a three-engined machine. General Brancker in his paper refers to the fact that we have had little experience of three-engined machines. Other countries, Belgium, for instance, are running a most successful service from Kinshasa to Luebo in the Belgian Congo with three-engined machines, with landing grounds 200 miles distant from one another, separated by virgin forest and jungle. As a result of the regularity of the service the increase in the load carried is surprising. It has grown from 300 kilogrammes to 2,000 kilogrammes per trip, and they run one, two, or even three machines. When we in this country come to three-engined machines we shall get equal results.

With regard to engines arranged in tandem, there may be some advantages; there is no turning moment when the rear engine cuts out, but when the front one cuts out the conditions are so upset that the results are nothing like so good as one would expect. We had this trouble in the big four-engined machine we constructed.

For real progress we must have reliability. It is no use considering paying loads per horse-power until you have got reliability. We must have multi-engined machines that, if weather conditions are bad, will get the pilot safely to land. Machines must have good flying control. We want reliable machines with good control at low speeds.

Major F. M. GREEN said: We have already heard the blame shifted from the pilots to the aeroplane constructors and now Mr. Handley Page passes it on to the engine builders. If you assume that the average length of flight is 300 miles, then instead of saying that the engine stops on every 45th flight you say that if there is one engine failure in over 13,000 miles it does not sound so bad. At the same time I do entirely agree with Mr. Handley Page that if we are to have really good progress, air transport must be safe and regular and that the traffic will not alter until this happens. I do not think we can make a single-engine machine that is entirely immune from engine failure. It is not always the fault of the engine that failure occurs. There are a lot of little things that may happen with the installation. I agree that multi-engine machines look to offer the best chance of success.

With regard to stability, I do not think that modern aeroplanes are as bad as General Brancker suggests. The B.E.2.c was exceptionally stable, but some at least of the commercial aeroplanes flying have a reasonable margin of stability. I do not think that increasing this margin will render them immune from accident, but I quite agree that a positive margin of stability is essential.

I am glad that the author of the paper has such hopes from the air-cooled engines. I share his views. I am not at all sure that the change-over to a sleeve valve system will increase the reliability of the engine. It certainly eliminates the chances of valve breakage, but possibly it introduces other possibilities of failure. The trouble with a valve breakage will of course depend on the type of engine used. In an air-cooled engine a valve breakage usually does not put the engine out of action, and as the cylinders are single units the repair is generally an easy matter.

I do not think that General Brancker has made out his case in assuming that the cost of running the aeroplane is directly proportional to the horse-power. I do not think that if we halved the horse-power of the engine on a given aeroplane the running costs would be halved; in fact, it is fairly obvious that this is not so.

General Brancker has given us a very interesting paper, and I am sure that all designers of commercial aeroplanes will join me in thanking him particularly for the valuable tables that he has drawn up.

Major WIMPERIS said: I have listened to Sir Sefton Brancker's very characteristic paper with great interest. I note that he relies upon designers and scientific men to help Civil Aviation with its problems. I am sure that the designers are doing so, and the firms that employ them are helping them with research problems. So far as the Governmental side is concerned we are doing, and shall continue to do, our best to help.

One of the most striking tables given by Sir Sefton Brancker is that in which the fuel and oil costs are given as 30 per cent., and engine maintenance as 44 per cent., of the total cost. Added together, one finds no less than 74 per cent. of the operational costs put on the shoulders of the engine in one way or another. The Author shows how they might be reduced and I think he is broadly justified in his assumptions. On the research side I see so many things happening in respect of engine developments that the future is, I think, a rosy one. But these things take time to develop, and even when they have got to the stage of being handed over to the practical man, questions may arise which entail the whole thing being remitted back to the research side for further exploration.

There is the possibility of increasing the horse-power of an engine by boosting. A large increase is possible, but you have to balance this with the weight of the extra machinery before the net effect can be seen. The use of heavy oil is coming very much to the fore, and is making progress at a greater rate than could have been foreseen as little as two years ago. Another possibility in course of experiment is the use of "doped" fuel. It does not offer quite as big a measure of improvement, but is worth considering.

Slot and aileron control offers improved control just at the point where the pilot most needs it. The gyro rudder work is in a promising condition from the point of view of Civil Aviation. It has been tried for some while and has got through most of its early troubles.

As regards machines as a whole, one speaker rather suggested that we had arrived at a nearly fixed type, but with this I do not agree; there are many possibilities still ahead of us.

The Council hope to approach Senor de la Cierva to lecture to us shortly about his autogyro, which, whatever its merits, certainly deviates remarkably from any fixity of type. It looks like a helicopter without, however, being one. It has four rotating blades and the inventor promises considerable advantages over the present type of aeroplane. We shall study its performance with interest. I mention this as one instance of the general proposition that we are not at the end of aeroplane evolution by any means. Perhaps I am rather in a favourable position to hear about new schemes; certainly my opinion is that as regards aeroplanes and engines we are really only just at the very beginning of our work.

Major MAYO said: I think that the impression that some of the pilots have got—that General Brancker was somewhat criticising them—is a wrong impression. It may have been caused by one or two expressions that he used. The sentence beginning, "From the beginning of aviation the designer has always been prone to assume that his aircraft would be flown by an absolutely first-class pilot . . ." might be an instance. The designer assumed that and he got it. The pilots who fly these machines are the very best obtainable, and the standard of skill displayed is a very high one. The designers have very rightly assumed that they would get the best piloting. Handling a large multi-engined machine in the sort of weather experienced on European routes requires a very high degree of skill, and a great deal of responsibility is placed on the shoulders of the pilot

when trouble develops. In future designs we must continue to assume that we shall have the best possible pilots, but designers ought to try and make their task as easy as possible. The most important aspect of this question is controllability. One of the chief reasons why the single-engined machine has done so well is that the D.H.34 is a machine which is exceptionally good in its controllability, and I was hoping that we should have some remarks from Mr. Hinchliffe to the effect that controllability is so important that it outweighs the question of engine reliability. I have heard him say that he would rather fly a machine that did occasionally have a forced landing, provided that it had a high degree of controllability, rather than a machine of greater reliability that was slow and heavy on its controls. As you probably all know, Mr. Hinchliffe has had very wide experience with all types of commercial machine.

We seem all to be agreed that we have got to come to the large three-engined machine, and it is absolutely essential, that being so, that we should pay the utmost attention to the question of controllability. I, personally, thoroughly agree with General Brancker when he emphasises the importance of controllability. I have never believed that controllability and stability are not attainable in the same machine, and I look forward to the day when we shall get back to the completely stable machine, and shall embody in it all the improvements in control that have become available during the last few years.

I thoroughly agree with Dr. Hele Shaw with regard to the importance of variable pitch propellers. From the commercial aviation point of view the big question is "get off." You cannot get a commercial machine off with the full load it would carry because you have not enough power to accelerate it quickly enough to its flying speed. Sir Sefton said that the D.H.34 used 480 h.p. to get off, and the real significance of that statement is that a large proportion of the power provided by the engine is wasted. Of course you can design an ordinary propeller to give a better take off, but the disadvantage of that is that when you get to anything like your full speed your engine will race and you will have to throttle it down considerably. The variable pitch propeller will enable the engine to be run at full revolutions both during the take off and when flying at full speed.

Wing Commander T. R. CAVE-BROWNE-CAVE moved a vote of thanks to Sir Sefton Brancker for his paper and to Major Mayo for reading it and taking charge of the meeting. It was valuable to have a clear statement of requirements because it enabled one to gain a view of them in proper perspective rather than from one single angle.

Of the various factors which contributed to unreliability and cost the pilots certainly had gained the greatest distinction in the searching criticism of the lecture.

The real villain was the engine. It was responsible for 70 per cent. of the cost and 40 per cent. of the failures. The only logical judgment was to allot to it, say, 55 per cent. of the funds available for research and development.

REPLY BY MAJOR-GENERAL SIR SEFTON BRANCKER, K.C.B., A.F.C., F.R.AE.S.

I very much regretted my absence on October 1st and my consequent inability to hear the criticisms on my paper and answer them at once; this regret is intensified now that I see that several pilots interpreted some of my statements as a direct criticism of their ability. This was the last thing in the world I intended to do; I have always said that the pilot was the most important factor in air transport and that everything depended on him; no one realises better than I do that our remarkable immunity from accidents has been very largely due to the extraordinarily high standard of efficiency displayed by British civilian pilots. It

is difficult to find a better description for the causes of the accidents enumerated than "error of judgment." If there are fifty alternatives and only one of them is right, and if one of the other forty-nine is selected, this constitutes an "error of judgment," although no one could criticise the pilot seriously for his action. Both Captain Barnard and Captain Hinchliffe are well aware of my keen appreciation of the great importance of the pilot as a factor in air transport, and, without criticising them in the least, I was most anxious to emphasise the necessity of improving the flying qualities of commercial aircraft and so relieving the pilot of some of his many responsibilities.

Captain Barnard thinks I laid too much stress on the necessity of increasing the paying load. This may be so, but we must strive unceasingly towards making air transport pay its way without artificial assistance, and, after establishing safety and regularity, the main problem will be to reduce the cost per ton-mile. Captain Barnard considers that we shall have to come to wireless telegraphy as opposed to telephony for air navigation. I agree with him; actually international regulations insisting that all aircraft capable of carrying ten or more passengers shall be equipped with wireless telegraphy have been drawn up. These regulations would have been brought into force on January 1st, 1926, but at the last meeting of the International Commission for Air Navigation the French delegates pleaded for another year's delay as they were not ready to put the regulations into force.

Captain Barnard suggested that a quickly removable power unit with tanks, etc., complete will be the best method of ensuring proper engine inspection and maintenance without undue delay at stopping places. I agree that this is an attractive idea. Actually, the D.H.18 and the D.H.34 were designed so that the engine itself could be removed by releasing four bolts. This system covered the engine only and involved the undoing of all petrol, oil, and water pipes, and the controls, and actually the time taken for these operations was too great to permit of the engines being removed at the end of a stage. This is a proposal which designers should consider carefully; the introduction of three-engine machines, however, will rather complicate the problem.

I am delighted to hear Captain Barnard say that in present conditions, all going well, a good pilot should be able to fly the cross-Channel trip on 362 days in the year. If this is so, it should not take very long to attain a regularity equal to that of trains and ships.

Captain Hinchliffe indicates that crashes occur the causes of which are never discovered. As Director of Civil Aviation, I have to approve of all reports on accidents, both military and civil, and it is extraordinary how very few remain unexplained. Actually in Civil Aviation we have never failed to discover the cause of an accident, except in one case in which the investigation was removed from the hands of the Inspector of Accidents. He quotes a particular case where a wind screen broke in the air; if on that occasion a serious accident had occurred, I think from my experience of other similar accidents that there is little doubt that a fragment of the wind screen would have been picked up some distance from the crash which would have indicated what had happened.

Captain Hinchliffe's comments on fast landing and controllability are very interesting and should be borne in mind when testing new aircraft which claim a very low landing speed.

Dr. Hele Shaw, in his wish to make good my apparent slur on the reputation of the pilots, has swung too far in the opposite direction when he talks of the "terrible dangers" which pilots have to contend with. Air transport has really proved itself to be a very safe and healthy profession. I think pilots will agree with me that it is their great responsibilities which they feel and not the danger. I am afraid that Dr. Hele Shaw's suggestion that an engine should be maintained always at its highest efficiency whatever the atmospheric resistance would throw

far greater strains on the power plant than is the case to-day where we fly well-throttled back with a good deal of power in hand.

I agree with Mr. Handley Page that it is very largely due to the skill of the pilots that there have been so few accidents, but I would like to add to that sentence "with existing aircraft and engines."

I am glad to see that Major Mayo states that he does not believe that controllability and stability are not obtainable in the same machine. If this is so, it makes a strong case for developing inherent stability in aircraft instead of depending on some form of automatic device.

Finally, after another opportunity of studying air transport in the East, I have come back more fully convinced than ever that metal construction and air-cooled engines are of utmost importance in the future development of air transport.

NOTE ON THE LONGITUDINAL STABILITY OF AEROPLANES WITH SPECIAL REFERENCE TO TAIL PLANE DESIGN

BY W. LAURENCE LE PAGE,

MASSACHUSETTS INSTITUTE OF TECHNOLOGY, U.S.A.

The problems of aeroplane stability in flight have been studied very thoroughly, both practically and in theory. Extensive mathematical investigations have been carried out by such men as Bairstow, Bryan, etc., and it is largely due to this work that the numerous questions arising with regard to the stable flight and equilibrium of the aeroplane are so well understood.

Nevertheless, though the work of these investigators is undoubtedly of primary importance, a discussion of the more practical aspects of the subject will be more within the scope of the designer. It is proposed in the present paper to deal with but one form of stability, namely, longitudinal, and to discuss the requirements of practical design together with the methods of complying with these. The question, therefore, resolves itself into an investigation of the main points controlling the size and setting of the tailplane of the aeroplane.

It must be remembered that the downwash has a very important bearing on the longitudinal dihedral adopted in the design and consequently this must be considered carefully. It is not accurate enough to merely accept the angle of downwash as being equal to one half the angle of attack of the wings measured from no lift incidence. In the preliminary stages of the design this angle should be calculated from the equation :—

$$w = A/\pi\rho v l^2 \, (1 + a/d)$$

in which

$$a = \sqrt{\{(l/2)^2 + d^2\}}$$

d = distance behind the wing.
v = velocity of flight.
w = vertical velocity component of downwash.
l = span.
A = lift.

The angle of downwash is subsequently obtained from

$$\tan \delta = w/v.$$

The longitudinal stability of an aeroplane is governed by the presence of a restoring couple of greater magnitude than the pitching couple. Considering these separately it will be seen that the pitching couple is compounded of :—

(1) The weight of the machine.
(2) The distance between the C.G. and the C.P.
(3) The magnitude of the airscrew thrust.
(4) The distance between the centre of thrust and the centre of resistance of the complete machine.

On the other hand, the restoring couple comprises :—

(1) The area of the tail plane.
(2) The angle of the tail plane to the downwash.
(3) The velocity of the downwash.
(4) The section of the tail plane has an important bearing on the restoring couple if it is not symmetrical.

The pitching couple is, however, hardly affected, except in flying boat designs, by the position of the centre of thrust, and consequently it will be accurate enough in most cases to define this as the product of the weight of the aeroplane and the horizontal distance between the centre of gravity and the centre of pressure. The vertical position of the C.G. with respect to the chord line in a monoplane and the horizontal line of travel of the C.P. (of the combined planes) in a biplane, are important factors in the determination of the size of the tail plane, for the C.G. in most designs is below the C.P. of the wings. Reference to Fig. 1, (*a*) and (*b*) will make this clear.

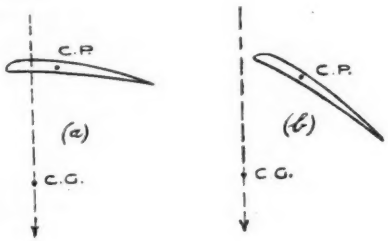

FIG. 1

When the incidence is small the horizontal distance of the C.G. from the C.P. is small and therefore the couple tending to make the angle of attack smaller is diminished. When the angle is large the couple tending to prevent a stall is large. This point is favourable for it assists in the action of the tail plane in preventing a stall at high angles and a nose dive at small angles.

In the design of a tail plane the angle to the downwash and the area are interdependent features, and it is these factors which govern the general "feel" of the machine in flight, or, in other words, the degree of stability, which is determined by the excess of the restoring couple over the disturbing couple. Reasonable "stiffness" in an aeroplane is necessary in order that oscillations may be damped out rapidly, and this demands that the rate of change of restoring couple be in excess of the rate of change of the disturbing force. It must be pointed out, however, that in order to adjust these factors it will not be possible to alter the size of the tail without a corresponding alteration in the angle setting, if it is desired that the machine shall trim at the same speed.

It will be seen then that the speed of the aeroplane has a marked influence upon the degree of stability. If, by an alteration of the engine unit, the maximum speed is increased from 90 to 130 miles per hour, the load on the tail will be increased in the proportion $130^2/90^2$ or 2.09 times. That is, the restoring couple at the attitude of top speed will be far and away greater than that required to trim at that speed, and the longitudinal dihedral angle will have to be decreased. At low speeds the result of this change will be that, in view of the large angle of attack of the complete machine and the smaller longitudinal dihedral, the tail will be at a larger positive incidence and the tendency for the machine to stall reduced.

The first and chief point to be decided upon in tail plane design is what angle of attack—*i.e.*, at what speed—it is required that the machine shall balance. That is, where shall the vertical line through the centre of gravity cut the longitudinal locus of the centre of pressure. If at maximum speed the C.G. is vertically below the C.P. and the machine consequently balances with no force on the tail, then, to conform with the conditions at slow speeds, in order to produce a couple tending to prevent the machine from stalling, the area of the tail will have to be very great, since its angle cannot be altered from its zero moment setting for

top speed. This is structurally absurd and, furthermore, at a speed above the normal maximum the force on the tail will throw the machine on its back. Conversely, if the C.G. is arranged vertically below the C.P. at minimum speed (C.P. farthest forward) and balance made there, then the tail will necessarily tend to stand the machine on its nose at all speeds above the stalling speed.

The requirements then are twofold. At top speed or the speed at which it is decided to trim, there should be a moment produced by the tail equal to the product of the weight of the machine and the horizontal distance between the centre of gravity and the centre of pressure. At the same time the tail must raise the nose of the machine as the speed increases and raise the tail as the speed decreases and stalling is approached. A compromise has to be arranged, for whilst a small dihedral, to allow for a large positive angle of the tail at slow speeds, is favourable to prevent stalling, at the same time provision must be made for equilibrium in a dive where the speed increases above the normal maximum, and where, if there is not sufficient negative tail incidence, the machine will turn over on its back.

The loading must, of course, be taken into account when considering the combination of area and angle of the tail plane, and this arranged within the limits of construction, allowing a suitable factor of safety to cover the diving condition.

It is necessary to decide upon the possible limit positions of the centre of gravity in terms of the wing chord, and from a knowledge of the general particulars of the design, calculate the pressure required on the tail at the speed of trim previously decided upon. The following formula is applicable :—

$$P = WC\,(p-g)/L$$

where

P = pressure on tail in pounds.
W = total weight of aeroplane in pounds.
C = wing chord (feet).
L = tail leverage about C.G.
p and g = respectively the positions of C.P. and C.G. in terms of the chord.

The leverage of the tail must be approximated as its centre of pressure is not known. The position of the leading edge can be taken for this.

The area of the tail will be found by dividing this pressure by the loading per square foot already agreed upon. The lift coefficient must be determined by substituting these values for P and A in the usual equation :—

$$C_L = P/AV^2$$

and from curves of aerodynamic characteristics obtained from wind tunnel tests upon the particular section adopted, the true angle of incidence of the tail can be read off.

The angle of downwash having been previously calculated from equation (1) the longitudinal dihedral (Fig. 2) is obtained directly.

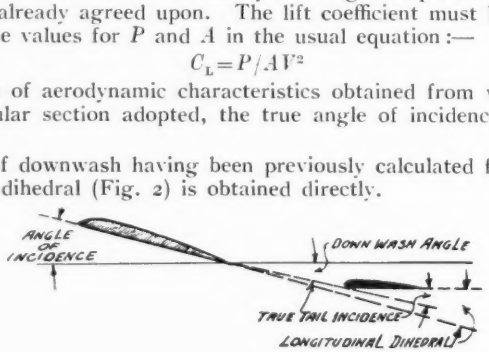

FIG. 2

In the above calculation two possible extreme positions of the C.G. should be taken and the tail plane designed to conform with the worst case.

It must be remembered that in a nose dive at limiting speed the load sustained by the tail is considerably in excess of that at top speed flying horizontal and for this reason it is advisable to determine whether the factor of safety allowed is high enough to permit of this extreme case. Consider the case of the machine in a nose dive. There will be a diving moment on the wings which must be overcome to prevent the machine from turning on to its back. This, however, will have been taken care of in the condition for horizontal flight, as is shown in Fig. 3. But in order to keep the machine in the dive it will be necessary to

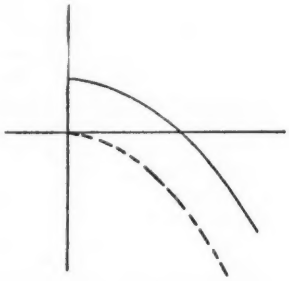

FIG. 3. PITCHING MOMENT

reduce the excess of positive pitching moment by lowering the elevators, thus dropping the curve to that depicted by the dotted line. The total moment on the machine will now be zero, though there will still be a down load on the tail to correct the diving moment on the wings. The force on the wings will be excessively high owing to the high limiting speed and the force on the tail will therefore be proportionately large. From a knowledge of the characteristics of the wings and the value of the limiting speed, the load on the tail can be calculated. It is then only necessary to decide whether the prearranged factor of safety for the tail is suitable.

From the foregoing discussion it will be realised how important it is to form a careful estimate of the loads to which the tail plane is to be subjected under various conditions of flight. The danger in altering the incidence of an already highly loaded tail, in order to correct a design, without careful consideration of the points herein discussed, will be apparent. Trial calculations should be made for extreme positions of the C.G. and the worst case allowed for. In this way it should be possible to design the tail such that little, if any, alteration is subsequently necessary, except that which can be arranged for by the tail adjusting gear.

THE FLAPPING FLIGHT OF BIRDS.

BY PROFESSOR SIR GILBERT T. WALKER, C.S.I., SC.D., F.R.S.

In connection with gliding flight enough measurements of "lift" and "drag" have been made to enable us to calculate the conditions for success of an aeroplane fitted with wings of standard sections; but no attempt has been made, as far as the present writer is aware, to ascertain what would happen if a flying machine were fitted with wings of standard section and these were flapped in a rhythmical manner. Would it support and propel itself? Several authors, including M. F. Fitzgerald[1] and Colonel J. D. Fullerton in the previous issue of this journal, have discussed various portions of this problem; but instead of appealing to wind-tunnel determinations the latter has used such expressions as ρSUV or ρSUV^2 for the pressure on a wing of area S, where ρ is the density of the air and V, U are the component velocities along and at right angles to its surface. As we know, however, for a cambered wing the lift may be $.3\,\rho V^2$, instead of zero, when $U=0$.[2] When $V=0$ Colonel Fullerton (Rule 2) gives as the pressure ρSU^2 when the experimental value[3] is about $.59\,\rho SU^2$. I regret too that he does not indicate his authority for the inclination of the wing in his Fig. 4, where positions 4 and 5 have inclinations between 45° and 60°, and 6 to 8 between 70° and 90°. My visual observations of large slow-flapping birds as well as of gulls and crows make me sceptical of inclinations near the middle or tip of the wing exceeding 30°; neither do photographs seem consistent with larger angles. However, as I disagree with Colonel Fullerton in several respects, I would like to express the greatest obligation for the valuable data compiled by him in the Report of the Bird Construction Committee.

2. For those to whom the mathematical analysis of the following paper is intolerable, reference may be made to the summary at the end. The degree of accuracy attempted does not exceed five per cent., and the analysis has been simplified by ignoring the rise and fall of the bird's body when flying horizontally. We call n the number of complete flaps in a second of a bird whose length of wing, measured from the shoulder joint, is l, the velocity of the bird being V; so if the distance described in a complete flap is $2a$ we have $2an=V$. When considering the forces acting on a wing we shall take the shoulder joint as origin with the direction of V as axis OX, and OZ vertically upwards.[4] The longitudinal axis of the wing will be assumed to lie in the plane YOZ making θ with the horizontal line OY; also for simplicity we shall suppose that θ increases and decreases at a constant rate; thus, if the limits are $\pm\alpha$, we shall suppose during a down beat lasting time T, $\theta=\alpha\,(1-2t/T)=\alpha\,(1-4nt)$, assuming values α and $-\alpha$ at times $t=0$ and $t=T$. Then for a point P on the axis distant r from the shoulder the co-ordinates will be $(0,\ r\cos\theta,\ r\sin\theta)$ and the velocity V' will be compounded of $r\dot\theta$ along PR and V along PQ; its direction will lie in the tangent plane RPQ. Let us call $\rho LV'^2$ and $\rho DV'^2$ the lift and drag upon the wing per unit area near P, so that the direction of $\rho DV'^2$ will be that of V' reversed and of $\rho LV'^2$ at right angles to this in the tangent plane RPQ, which contains the normal to the plane of the wing at P. Thus we may replace $\rho DV'^2$ by $-\rho DV'.r\dot\theta$ along PR and $-\rho DVV'$ along PQ, while $\rho LV'^2$ yields $\rho LVV'$ along PR and $-\rho Lr\dot\theta V'$ along PQ. Resolving along the axes of co-ordinates we have $-\rho V'(Lr\dot\theta+DV)$ parallel to OX and $\rho V'(LV-Dr\dot\theta)\cos\theta$ parallel to OZ; the

[1] "On Flapping Flight," Proc. Roy. Soc., London, 83, p. 72, 1910. Here angles of incidence are not considered, but the resistance to acceleration of the wings is represented by a varying virtual addition to their mass.

[2] See Bairstow, "Applied Aerodynamics," pp. 123-7.

[3] *Ibid.*, p. 126.

[4] See Fig. 1.

component parallel to OY is of no consequence as it will be cancelled by the corresponding force on the second wing.

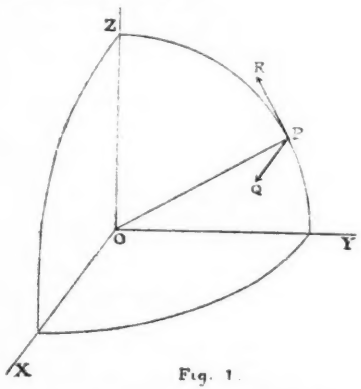

Fig. 1

During the time of a down beat, if the angle of incidence of the wing β be constant, L and D will be constant; thus the momentum parallel to OX produced in the time T by the lift and drag will be $-\rho V' \int_0^T dt\,(Lr\dot{\theta} + DV)$ or $\rho V'\,(2Lra - DVT)$ or $\rho V'\,(2Lra - Da)$. The upward momentum will be $\rho V' \int_0^T dt\,(LV - Dr\dot{\theta})\cos\theta$, and as

$$4n\alpha \int_0^T dt \cos\alpha(1 - 4nt) = 4n\alpha \int_0^T dt\,(\cos\alpha\cos 4nt\alpha + \sin\alpha\sin 4nt\alpha)$$
$$= \cos\alpha \sin 4nT\alpha - \sin\alpha\,(\cos 4nT\alpha - 1),$$

where $2nT = 1$, so $\int_0^T dt\cos\theta = 2\sin\alpha/4n\alpha$, and the upward momentum becomes $\rho V'\,(LV\sin\alpha/2n\alpha + 2Dr\sin\alpha)$, or $\rho V'\,(La + 2Dra)\sin\alpha/a$.

3. If L', D' be the coefficients of lift and drag during the up beat, the angle of incidence being another constant angle γ, the total momentum per unit area added during the term T of an up beat will be, in a similar manner, $\rho V'\,(-2L'ra - D'a)$ parallel to OX, and $\rho V'\,(L'a - 2D'ra)\sin\alpha/a$ parallel to OZ. Thus the average forward force during the time $2T$ of a complete beat will be $\rho V'\,\{\,2\,(L - L')\,ra - (D + D')\,a\,\}\,/2T$, or

$$\tfrac{1}{2}\rho VV'\,\{\,(L - L')\,2ra/a - (D + D')\,\} \quad . \quad . \quad . \quad (1)$$

and the average upward force will be

$$\tfrac{1}{2}\rho VV'\,\{\,(L + L') + (D - D')\,2ra/a\,\}\sin\alpha/\alpha \quad . \quad . \quad . \quad (2)$$

4. If ABC be the path in space of the point r of the wing,[5] this will be traced on the surface of a cylinder whose axis passes through the shoulder joint in the

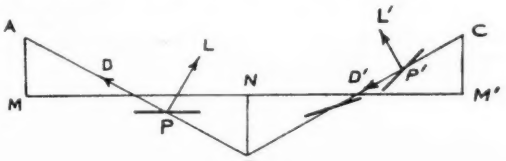

Fig. 2.

[5] See Fig. 2.

direction of V, and whose radius is r. The arcs AM, BN, CM' will be of length ra, while $MN=a=NM'$. Then if the cylindrical surface is unrolled into a plane AB will become a straight line inclined δ to MM' where $\tan\delta=2ra/a$; and in order that the expression (1) may be large the sum of the components of (L, D) and (L', D') along MM' should be large, while (2) is proportional to the sum of the components of these along MA.

Now a gliding bird has enough lift with its wings fixed, but will have an appreciable drag, and the object of flapping is to get an adequate propulsive force. Also the inner portion of the wing, *i.e.*, the portion for which r is small, will have ABC nearly straight, and with δ small we can get lift but no appreciable propulsion. The forward drive must come from the outer portion of the wing.

5. We must now use actual numbers and I have chosen the rook as a good flyer for which some approximate information is available. Here[6] the weight $W=1.1$ lbs., $n=4$, $V=36$ ft. sec., $\delta=1.3$ sq. ft. and $l=1.4$ ft. (the span being 3.15 ft.). Thus $a=4.5$, so if the wings flap through a right angle and $\alpha=\pi/4$, $2la/a=.49$.

For the ordinary Indian vulture (*gyps bengalensis*) my estimates are $l=3$, $V=40$, $n=1.6$, $W=10$, $S=7$; so $a=12.5$ and $2la/a=.38$.

The ratio $2la/a$ of the flapping velocity of the wing tip to the forward velocity of the bird, which we shall call k, is of considerable importance; when a bird wishes to produce a large propelling force, as when starting or climbing steeply, n and therefore k is increased, while when flying downhill or stopping k is diminished. It is of interest to collect such values of k as are available. From the Bird Construction Committee's report, §35, p. 15, we can derive ratios of the velocity of the centre of pressure of the wing to V and multiplying by 3/2, from the velocity of the wing tip, to get $2la/a$, we find for the pigeon .3, pheasant .35, rook .35, partridge .3 and herring gull .4. For the rook I have taken .42 as the mean of the two somewhat divergent values. Inasmuch as the propelling force in (3) below is roughly proportional to k, too small a value may lead to failure in that force.

6. We must now put (1) and (2) into a form suitable for evaluation. Since $V'^2=V^2\{1+(2ra/a)^2\}$, $V'=V(1+\frac{1}{2}k^2r^2/l^2)$, omitting negligible terms. Thus for (1) we have

$$\tfrac{1}{2}\rho V^2(1+\tfrac{1}{2}k^2r^2/l^2)\{(L-L')kr/l-(D+D')\} \quad . \quad . \quad . \quad (3)$$

while the upward force is

$$.45\,\rho V^2(1+\tfrac{1}{2}k^2r^2/l^2)\{(L+L')+(D-D')kr/l\} \quad . \quad . \quad (4)$$

We shall now suppose that the inner portion of the wing devoted to lifting extends from $r=0$ to $r=l/3$, one third of the length. From these portions of the two wings the forward force is, if S be the area of the two wings, and the angles of incidence are uniform along the portions,

$$(\tfrac{1}{3}S)(.5\,\rho V^2)\{(L-L')k/6-(D+D')\},$$

omitting terms of 1/100 of those kept, or

$$S\rho V^2\{.012(L-L')-.17(D+D')\}$$

Similarly the upward force is

$$S\rho V^2\{.15(L+L')+.011(D-D')\}$$

Regarding the remaining outer two-thirds as the propelling portion we shall have from it by (3) a forward force of

$$(2S/3)(.5\,\rho V^2)\{(L-L')(2k/3+5k^3/27)-(D+D')(1+13k^2/54)\}$$

yielding

$$S\rho V^2\{.098(L-L')-.35(D+D')\}$$

while the corresponding upward force is

$$S\rho V^2\{.31(L+L')+.088(D-D')\}$$

[6] Report of the Bird Construction Committee, pp. 33, 61.

7. In order to get a big propelling force we note that the terms from the down beat are $S\rho V^2 \{ .098\, L - .35\, D \}$, so taking a high velocity wing, R.A.F. 15 (with a big ratio of L/D) and $\beta = 8°$, we have from Bairstow's Applied Aerodynamics $L = .387$ and $D = .0277$; for the up beat we want L' negative, so we suppose the angle of incidence negative and in order that L' may be numerically large assume the wing flat during this half stroke. That the wing is flatter during the up beat than the down beat is suggested by its being more relaxed at this time, and it is clear that when a bird is requiring a high lift at low velocity its wings, when gliding, are straight and taut, while when gliding slightly downhill at high velocity they are relaxed. So for the up beat of the rook we take $\gamma = -5°$ (Bairstow, p. 126) with $L' = .177$, $D' = .025$. Then the average forward force is

$$S\rho V^2 \{ .098\, (.387 + .177) - .35\, (.028 + .025) \}$$

or $.037\, S\rho V^2$. The upward force is

$$S\rho V^2 \{ .31\, (.387 - .177) + .088\, (.028 - .025) \}$$

or $.069\, S\rho V^2$.

8. The area A of cross section of the rook's body at right angles to the direction of flight is about .07, or $.054\, S$; this is in rough agreement with the values in Table 1 of Fullerton's paper from which we can deduce ratios of A/S for the teal, grouse, stork, swift and starling amounting to .028, .055, .064, .031 and .116. Thus, as the resistance to a corresponding airship envelope is between $.025\, \rho A V^2$ and $.03\, \rho A V^2$ (Bairstow, p. 203), the resistance of the rook's body is about $.027\, \rho\, (.054\, S)\, V^2$ or $.0015\, \rho S V^2$.

Thus we have a forward force of about $.035\, \rho S V^2$ available for overcoming the backward drag of the inner third; in other words, for that portion

$$-.035 = .01\, (L - L') - .17\, (D + D')$$

while the upward force from it is

$$S\rho V^2 \{ .15\, (L + L') + .01\, (D - D') \}$$

Obviously little is gained by making β and γ unequal for the down and up beats of the inner third; if they are equal the former equation gives $D + D' = .21$, corresponding to $\beta = \gamma = 14°$ for a high lift wing, R.A.F. 19. The corresponding lift is $S\rho V^2 \{ .15 \times 2 \times .845 \}$ or $.253\, S\rho V^2$; adding to this the lift of $.069\, S\rho V^2$ from the outer portions we get $.32\, S\rho V^2$, or .65 lbs. The bird's weight is, however, 1.1 lbs. or $.52\, S\rho V^2$ and this scheme is inadequate.

9. The lift derived from an incidence of 14° from the inner portion cannot be increased appreciably, and it is clear that we must increase the lift of the outer two-thirds; and simple analysis shows that this is best effected by increasing L and reducing D' as far as possible; changes in D and L' matter little. So we take for the down beat $\beta = 14°$ with high-lift section R.A.F. 19, and for the up beat $\gamma = 0$ with high-velocity section R.A.F. 15; then from the outer portions we have forward force

$$S\rho V^2 \{ .098\, (.845 - .057) - .35\, (.101 + .008) \} \quad \text{or} \quad .039\, S\rho V^2$$

and for the lift

$$S\rho V^2 \{ .31\, (.845 + .057) + .088\, (.101 - .008) \} \quad \text{or} \quad .29\, S\rho V^2.$$

For the inner portion we may have a horizontal resistance from the wings not exceeding $.037\, S\rho V^2$; thus $.34\, D = .037$ and D must not exceed .11. If then $\beta = \gamma = 14°$, $D = .101$, and there is a slight excess of propelling force amounting to $.003\, S\rho V^2$, while the lift of the inner portion is $S\rho V^2\, (.3)\, (.845)$ or $.253\, S\rho V^2$. The total lift from the wings is thus $.54\, S\rho V^2$, which will support a weight of 1.13 lbs. and just suffices.

10. In view of the discontinuity at $r = l/3$ it seems worth while to consider

the effect of dividing the wing into three equal parts and it is easily shown that the propelling and lifting forces on the outer thirds are

$$.062\,(L-L')-.18\,(D+D'),\ \text{and}\ .16\,(L+L')+.056\,(D-D');$$

and on the central portions they are

$$.036\,(L-L')-.17\,(D+D'),\ \text{and}\ .15\,(L+L')+.032\,(D-D').$$

For the inmost portions we have already found

$$.012\,(L-L')-.17\,(D+D'),\ \text{and}\ .15\,(L+L')+.011\,(D-D').$$

During the down beat we had $\beta=14^\circ$ with a high-lift section all along the wing, but for the up beat we had $\gamma=14^\circ$ with a high-lift section from $r=0$ to $r=l/3$, and $\gamma=0$ with a high-velocity section from $r=l/3$ to $r=l$. It is natural to try the effect of $\gamma=-4^\circ$ in the outer portion, flat or R.A.F. 15, and of $\gamma=+4^\circ$ in the middle portion with section R.A.F. 15. The change to -4° flat gives an increased propulsion of $+.010\,S\rho V^2$ and lift of $-.033\,S\rho V^2$: the change to -4° R.A.F. 15 would add $.008\,S\rho V^2$ and $-.023\,S\rho V^2$; and the change to $+4^\circ$ in the middle portion would add $-.008\,S\rho V^2$ and $+.027\,S\rho V^2$.

Now an *addition* of $.014\,S\rho V^2$ to the lift would enable us to reduce the angle of incidence of the inner portion from 14° to 12° and so reduce the resistance by $.005\,S\rho V^2$: a decrease in the lift cannot be met in this way, for increasing from 14° to 16° diminishes the lift of R.A.F. 19. So we must not make γ negative in the outer third; but in the middle third if we increase γ to 4°, the diminution of lift in the inner third section allows us to diminish the drag there by $.009\,S\rho V^2$, so that the net change is an increase of driving force of $.017\,S\rho V^2$. If we change to 8° in the middle third we add $.049\,S\rho V^2$ to the lift and lose $.015\,S\rho V^2$ in propulsion. So we may improve our design by increasing γ to 4° or 8° in the middle third and diminishing the angle of incidence in the inner third to 12° or 10°.

Summary

The conclusions reached from an approximate numerical analysis of the flight of a rook, based on measured properties of aerofoils, is that the necessary forces of lift and propulsion are forthcoming provided that the portion of the wing near the body is used for lift in both down and up strokes and has a large camber; it must have a fairly large angle of incidence, about 10°, with the high-lift section R.A.F. 19. The remainder of the wing is used for lifting and propelling during the down stroke, and has then essentially the same conditions as the inner portion of the wing; but during the up stroke the camber is materially diminished and the angle of incidence diminishes to zero as the tip of the wing is approached. Thus, if the angles of incidence during the down beat and the up beat are denoted by β and γ, we may divide the length of the wing into three equal parts; for the inner we may have $\beta=\gamma=12^\circ$; for the middle portion $\beta=12^\circ$, $\gamma=6^\circ$; and for the outer portion $\beta=12^\circ$, $\gamma=0$. The section throughout is the high-lift R.A.F. 19 except for the outer two-thirds during the up beat when it is the high velocity R.A.F. 15. Some latitude is permissible.

It follows that although we see birds with the plane of the wing twisted so as to have a bigger angle of incidence near the body than near the tip, we must not conclude that this feature is designed to improve gliding flight, for its object is, probably, to produce propulsion during flapping flight. Another outstanding feature in the wings of sea birds, such as gulls, is that the wing, instead of being straight, may be bent downwards through about 45°; and the object probably is that when they are rising from the water and have their wings inclined upwards at about 45° so as to flap clear of the surface, the half of the wing further from the body is not far from horizontal and is in a position for more efficient lifting.

REPLY TO MAJOR GNOSSPELIUS *

BY COLONEL J. D. FULLERTON, R.E. (RET.).

(1) Wings are of course flexible, as can easily be seen by handling them. In flight the necessary bending is produced by the air pressure. But the general camber of the whole wing can be varied by moving the joint which works the outer part of it. This joint corresponds to the wrist joint in a man's hand, and as both portions of the wing are connected any motion of the outer part varies the camber of the whole wing in any required manner.

(2) According to Lilienthal the cross section of a bird's body *decreases* in flight (see his book Pl. VII.), and he explains why this occurs. I may mention that some thirty years ago I visited Lilienthal in Berlin, saw his flights and discussed many matters with him. He was, I consider, an exceptionally careful observer and measurements taken by him are, I think, quite reliable.

(3) U has been taken as uniform because any other assumption would have made this paper far too long.

As regards the formula $U = 2BH$, the maximum value of U does not come into these calculations at all. As can be seen from Table III., it is only required when V is less than (for the Teal) 17.56 metres p.s., that is to say, when the bird is getting up in the air, viz., starting, which is not considered in the paper.

The fore and aft motion of the bird's body has been neglected as it appears to be very small in full flight. Marey's calculations were made for birds in slow flight, and in two cases the paths (see his Appx. Vol des Oiseaux) were not even horizontal.

(4) Lilienthal explains in his book why he takes $2W$ as the weight to be lifted, but the following explanation may be found simpler. On the down stroke some weight, say P, must be lifted, therefore in one such stroke the work $= PH$.

Since there are B down strokes per sec., work per sec. $= PBH$, but work per sec. also $= WU$.

$$\therefore PBH = WU = W \times 2BH.$$

hence

$$P = 2W.$$

If it is considered that W is lifted on each up and down stroke, then for one complete stroke

$$\text{work} = 2WH,$$

and since there are B complete strokes,

$$\text{work} = 2WH \times B = W \times U \text{ as before.}$$

(5) As regards the formula $P = \rho SV^2V$, I think this is quite clearly explained in the latter part of Rule 2. The volume of the block of air acted upon by the wing must be $V \times S \times V^2$ and the formula follows from this.

(6) There is nothing absurd about a stork being able to exert about the same power as a man. Lilienthal's calculations, practically speaking, agree with mine, and his are based upon very careful observations of speed and equally carefully made measurements of dead birds. As regards examination of birds' skeletons, who would suppose from looking at one of a swan that such a bird could, with one blow of his wing, break a man's leg; yet this has actually happened. Besides, it is well known that very great care is necessary when

* See October JOURNAL, p. 543.

handling large birds, as they are much more powerful than is generally supposed.

(7) The system adopted by Major Gnosspelius is the same as that used by Chanute for a pigeon in his book on Flying Machines. It is open to the objection that we do not know definitely whether the section of a bird's wing has any resemblance whatever to R.A.F. 15, in fact, as the latter has no flexibility, it is in all probability not in the least like it. Calculations based on R.A.F. 15 do not seem to me to be of much use.

Birds, of course, have a much better gliding angle than the present-day aeroplanes, the reason being that they have much better forms (regards both wings and bodies) and consequently the parasitic resistance is greatly reduced.

The experiments made with stuffed birds do not seem to be of much use, as the wings were not flexible, and flexibility is essential for tests of this description.

As regards the flights of small and large birds, the former in my opinion do fly the fastest, the reason being the formation of their wing joints which allows them to accelerate more easily (in other words, they have a much more flexible motor). Again, as far as I can ascertain, no large bird can fly more than about 70 miles per hour, while the Teal (whose flights were measured with exceptional care by Captain Gould) flew at the rate of 144 miles for 20 to 25 secs.

(8) It is very difficult to draw satisfactory deductions concerning a bird's wing by comparing it with the planes of an aeroplane. It has always seemed to me that the latter are constructed upon principles radically opposed to those on which a bird's wing is designed. The chief reason for this appears to be that the first experimenters wanted machines which could be easily made, and therefore constructed oblong planes with rear spars, simply because they were easier to make, not because they had any special aerodynamic features. Latter day designers use oblong planes for much the same reason.

(9) I quite agree that experiments should be made in bird flight. I am convinced that when machines are built upon the lines of a good fast flying bird we shall get far better results, both as regards speed, and what is even more important, stability. It is to be hoped that either the Air Ministry or other constructors will make a serious attempt in this direction.

CORRECTION.—On page 542, second line, paragraph headed *Stork*, *executed* should read *exerted*. Third line of paragraph headed *Common Swift*, for 113·7 read 1/13·7.

THE FLAPPING FLIGHT OF BIRDS

Colonel FULLERTON, R.E., writes :—

(1) Chanute in his book on "Flying Machines" calculated the velocities, power, etc., of a pigeon in the way suggested by the author. The great objection to using this method for birds is that the sections such as R.A.F.15, etc., tested in the wind tunnels, do not in any way resemble the section of a bird's wing, as they are hard and solid, and have no flexibility, one of the most important assets of a bird's wing.

(2) I have used the expression ρSU^2V because it is (omitting friction) a true value for any kind of wing, as can be seen from Rule 2 of my paper in the September number of the Society's Journal.

(3) When $V=1$ my value gives $(1)\times\rho SU^2$. The reason for this coefficient (1) (which has nothing to do with $V=1$) is that it is a suitable one, under the circumstances. The author's value = .59 is for a *flat plane*, and therefore cannot be used for the *curved wings* of a bird. I arrive at the figure (1) from the following considerations. According to Renaud the figure for a parachute is (1.2), and assuming the bird's wing curvature to be something between a plane and a parachute curve, (1) seems to be a suitable value.

(4) It is extremely difficult to show the mean inclinations of a bird's wing at the different stages of a stroke. Fig. 4 is based upon Marey's figure in Le Vol des Oiseaux (corrected as explained by him in a Note on p. 120). Allowance has also been made for the assumption that all the work is done on the down stroke, and that a wing resembles generally the blade of a totally immersed paddle wheel blade, the details of action of which can be seen in the usual text-books of Hydraulics.

(5) As regards the author's method of calculation, it is doubtful whether the length of the supporting part of the wing is $=\frac{1}{3}l$. The best French authorities consider the length of the "Fouet or Whip" to be $.4l$, thus making the supporting part $=.6l$. Airship envelopes are not a good guide for estimating the resistance of the bodies of birds. The models used were very smooth and highly polished, and had no *heads* such as birds have. The 1 16 I have taken may be too high, but I think it is a reasonable value, when all the circumstances are taken into consideration.

(6) Summary.—There may be a small lift during the up stroke, when it is assumed that work is done on both strokes, but judging from Marey's calculations for Capt. de Labouret's cinematograph experiments on a pigeon, it cannot be very much—see Appx., Le Vol des Oiseaux.

(7) I am glad to see that there are some members of the Society interested in bird flight, and I hope others will take the subject up, as I believe that machines constructed on the lines of fast-flying birds have a great future before them.

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